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August 1994

US Army Corps
of Engineers
Waterways Experiment
Station

Barking Sands, Kauai, Hawaii, Design of Proposed Harbor for Pacific Missile Range Facility

Coastal Model Investigation

by Robert R. Bottin, Jr.

Approved For Public Release; Distribution Is Unlimited

Prepared for U.S. Army Engineer Division, Pacific Ocean
and U.S. Navy Pacific Missile Range Facility

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Final report

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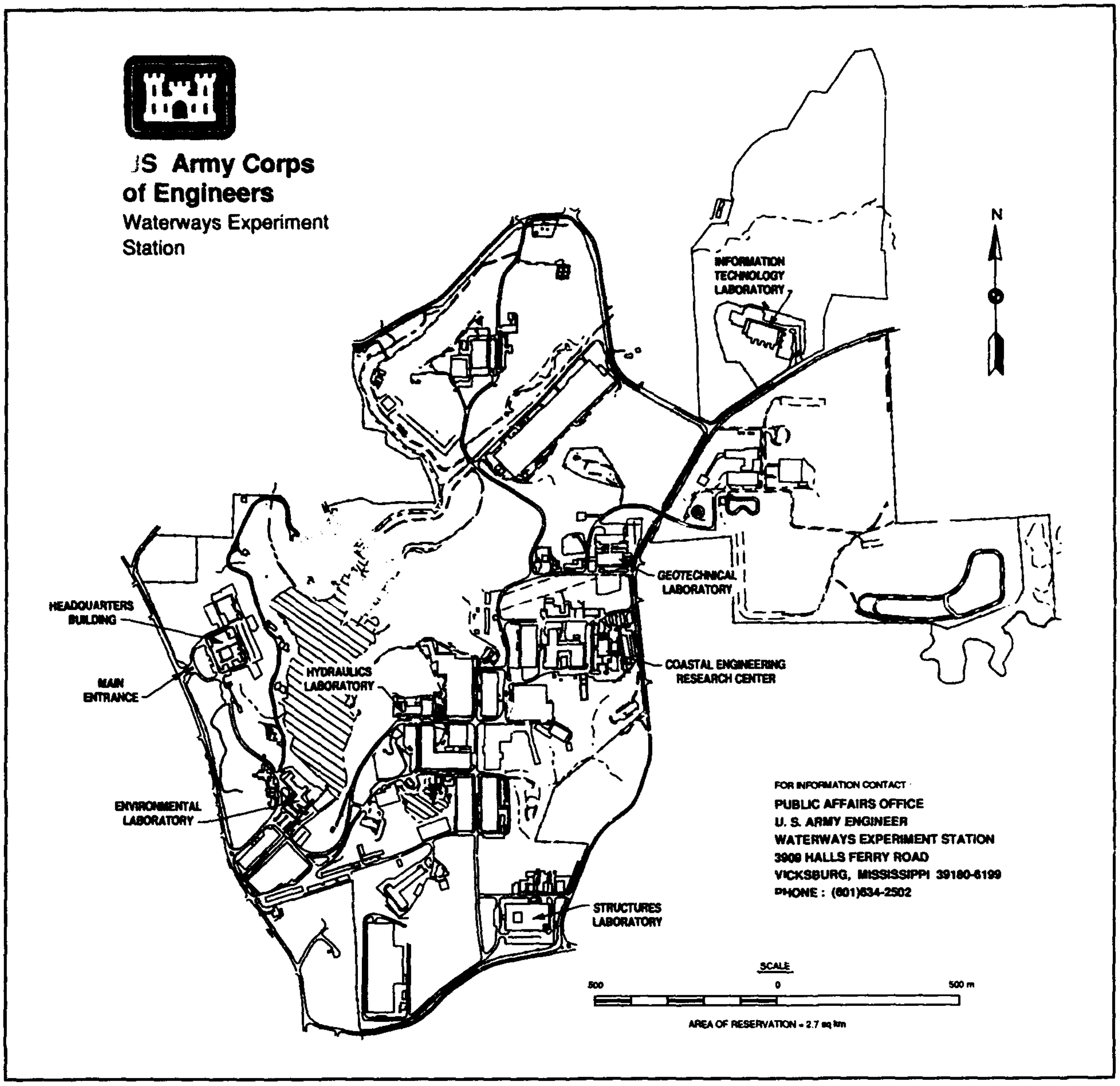

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Preface

A request for a model investigation of a proposed harbor at Barking Sands, Kauai, Hawaii, was initiated by the U.S. Army Engineer Division, Pacific Ocean (POD), in coordination with the U.S. Navy Pacific Missile Range Facility (PMRF). Authorization for the U.S. Army Engineer Waterways Experiment Station (WES), Coastal Engineering Research Center (CERC), to perform the study was subsequently granted by Headquarters, U.S. Army Corps of Engineers. Funds were provided by the U.S. Navy on 15 August 1986.

Model tests were conducted at WES during the periods February through March 1992 and November 1993 through January 1994 by personnel of the Wave Processes Branch (WPB) of the Wave Dynamics Division (WDD), CERC, under the direction of Dr. James R. Houston and Mr. Charles C. Calhoun, Jr., Director and Assistant Director of CERC, respectively; and under direct guidance of Messrs. C. E. Chatham, Jr., Chief of WDD; and Dennis G. Markle, Chief of WPB. Tests were conducted by Messrs. William G. Henderson, Hugh F. Acuff and Larry R. Tolliver, and Etienne Trahan, under the supervision of Mr. Robert R. Bottin, Jr., Project Manager. This report was prepared by Mr. Bottin.

Prior to the model investigation, Mr. Bottin met with representatives of POD and PMRF and visited the proposed Barking Sands harbor site. During the course of the investigation, liaison was maintained by means of conferences, telephone communications, and monthly progress reports. Mr. Stan Rollins of PMRF visited WES and observed model operation during the course of the study.

Dr. Robert W. Whalin was Director of WES during model testing and the preparation and publication of this report. COL Bruce K. Howard, EN, was Commander.

Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
acres	4046.873	square meters
cubic feet per second	0.02831685	cubic meters per second
degrees (angle)	0.01745329	radians
feet	0.3048	meters
feet per second	0.3048	meters per second
inches	25.4	millimeters
knots (international)	1.8532	kilometers per hour
miles	1.609347	kilometers
miles per hour	1.609344	kilometers per hour
pounds (force)	4.4482224	newtons
square feet	0.09290304	square meters
square miles	2.589998	square kilometers
tons (2,000 lb force)	8896.444	kilonewtons

1 Introduction

The Prototype

The U.S. Navy Pacific Missile Range Facility (PMRF) is situated at Barking Sands on the west coast of Kauai, the fourth largest island in the Hawaiian Island chain (Figure 1). The PMRF, established in Kauai in 1958, functions primarily to conduct, monitor, and evaluate U.S. Navy fleet training exercises involving multiple air, surface to sub-surface units, and to engage in testing and evaluation of weapons systems. The undersea ranges operated by PMRF for training and weapons testing cover 1,100 sq miles[1] of ocean to the northwest of Barking Sands.

The existing PMRF harbor facility is located at Port Allen, a state commercial harbor located approximately 20 miles southeast of Barking Sands. The present complement of vessels supporting range operations include 85-ft-long weapons retriever boats, 55-ft-long target boats, 38-ft-long utility boats, and 16-ft-long work boats. To support expanded range operations, PMRF will acquire a new class of vessels (120 ft long) for torpedo weapons recovery. It is anticipated that the older 85-ft-long weapons retriever boats will continue in service at PMRF as adequate berthing space can be made available.

The Problem

The space available at Port Allen is barely adequate for the existing PMRF vessels. When the larger vessels are acquired, the existing berthing area at Port Allen will not be sufficient for safe mooring and maneuvering. Also, during southerly storm conditions, Port Allen Harbor does not provide a secure berthing area for PMRF vessels. When adequate warning time is available prior to rough sea conditions, the weapons

[1] A table of factors for converting non-SI units of measurement to SI units is presented on page vi.

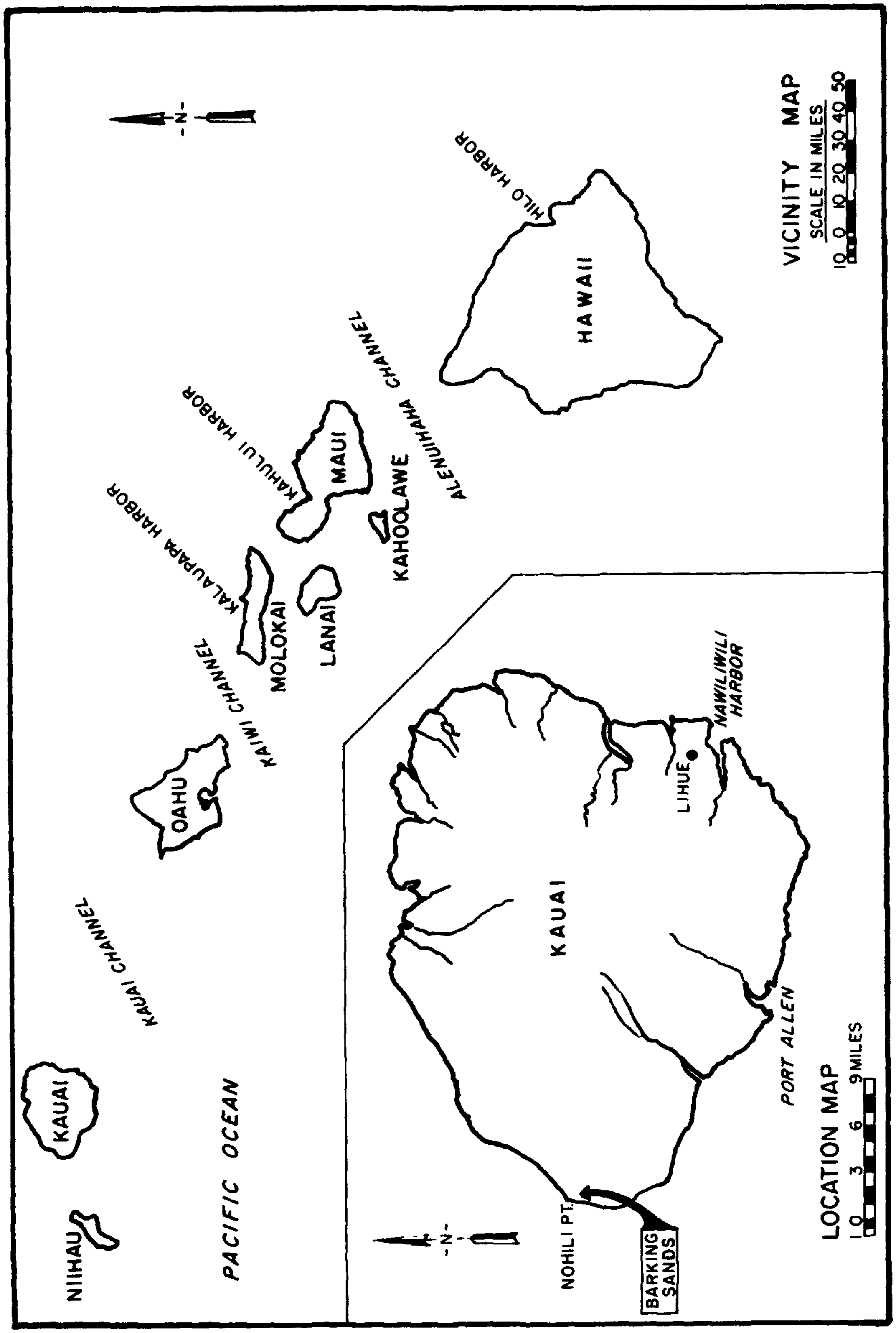

Figure 1. Project location

retriever boats are moved to Nawiliwili Harbor, and target boats are removed from the water. Without sufficient advance notice of storm conditions, substantial damages may be inflicted on PMRF craft. In 1982, two of the 55-ft-long target boats were destroyed at their moorings (U.S. Army Engineer Division (USAED), Pacific Ocean 1985).

Additional permanent space for shoreline facilities is desired by the Navy. The current warehouse space at Port Allen is limited and available on short-term leases; therefore, full development of essential warehouses and machine shops to support PMRF vessels cannot be accomplished. The Navy expends $100,000 per year in lease costs at Port Allen (USAED, Pacific Ocean 1985). In addition, with the existing harbor facility at Port Allen, the PMRF support vessels incur significant additional expense and lost time transitting to and from the range located northwest of Barking Sands. A one-way trip from Port Allen to the PMRF range takes approximately 2 hr. Besides the extra operating expenses, there are also additional costs incurred in transporting torpedoes via trucks to and from Port Allen.

Due to the above-mentioned problems, construction of a harbor is proposed at Barking Sands along the PMRF shoreline. The harbor would accommodate current and future Naval fleet assigned to Barking Sands and provide permanent space for shoreside facilities on Government-owned land. It also would provide storm wave protection for the PMRF vessels and be located in the proximity of the operating ranges. In an aerial photo (Figure 2), the shoreline at PMRF as well as the approximate location of the proposed harbor are shown.

Purpose of the Model Study

At the request of the U.S. Army Engineer Division, Pacific Ocean (POD), and the U.S. Navy PMRF, a physical coastal hydraulic model investigation was initiated by the U.S. Army Engineer Waterways Experiment Station (WES) to:

a. Study wave and shoaling conditions for the proposed harbor configuration.

b. Determine if proposed structural improvements would provide adequate wave protection in the berthing areas of the proposed harbor and shoaling protection in the entrance.

c. Develop remedial plans for the alleviation of undesirable conditions as found to be necessary.

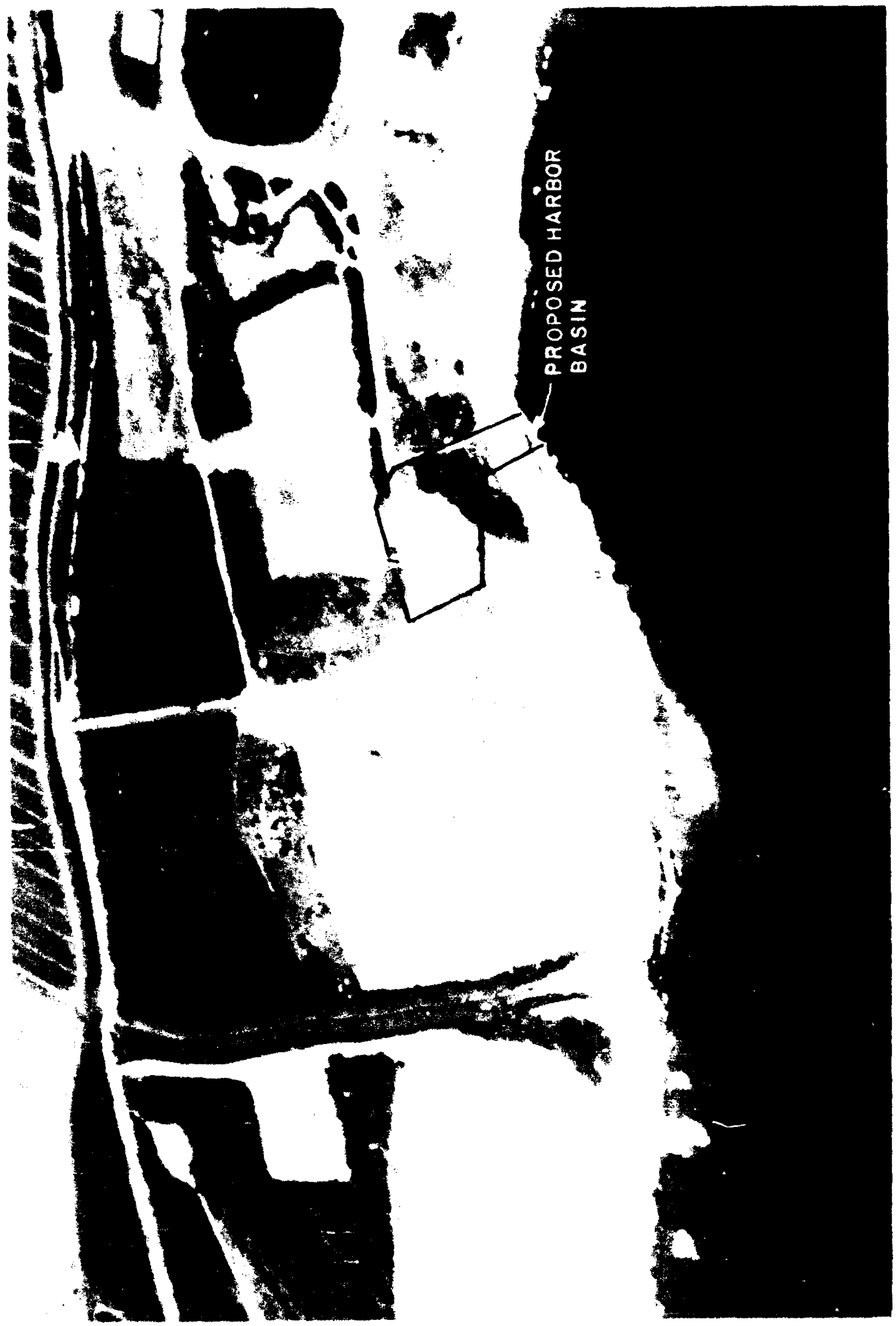

Figure 2. Aerial view of proposed project site

Wave Height Criterion

Completely reliable criteria have not yet been developed for ensuring satisfactory navigation and mooring conditions in small-craft harbors during attack by storm waves. For this study, however, POD specified that for an improvement plan to be acceptable, maximum significant wave heights were not to exceed 1.5 ft in the mooring areas of the proposed harbor.

2 The Model

Design of Model

The Barking Sands Harbor model (Figure 3) was constructed to an undistorted linear scale of 1:60, model to prototype. Scale selection was based on the following factors:

a. Depth of water required in the model to prevent excessive bottom friction.

b. Absolute size of model waves.

c. Available shelter dimensions and area required for model construction.

d. Efficiency of model operation.

e. Available wave-generating and wave-measuring equipment.

f. Model construction costs.

A geometrically undistorted model was necessary to ensure accurate reproduction of wave and current patterns. Following selection of the linear scale, the model was designed and operated in accordance with Froude's model law (Stevens et al. 1942). The scale relations used for design and operation of the model were as follows:

Characteristic	Model-Prototype Dimension[1]	Scale Relations
Length	L	$L_r = 1:60$
Area	L^2	$A_r = L_r^3 = 1:3,600$
Volume	L^3	$V_r = L_r^3 = 1,216,000$
Time	T	$T_r = L_r^{1/2} = 1:7.75$
Velocity	L/T	$V_r = L_r^{1/2} = 1:7.75$

[1] Dimensions are in terms of length (L) and time (T).

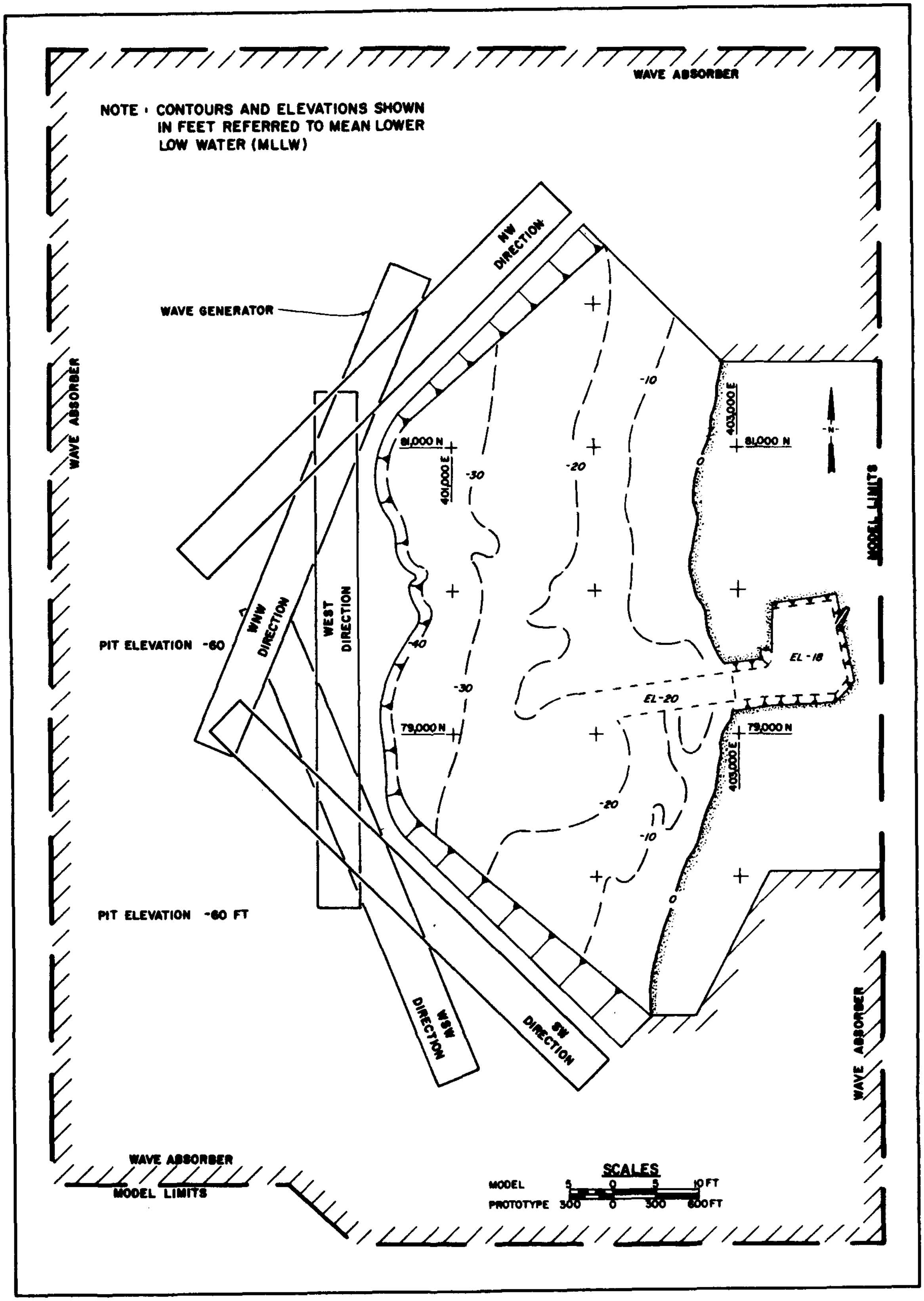

Figure 3. Model layout

The breakwaters and wave absorbers proposed for Barking Sands included the use of rubble-mound structures. Based on experience, 1:60-scale model structures should not create sufficient scale effects to warrant geometric distortion of stone sizes in order to ensure proper transmission and reflection of wave energy. Therefore, rock size selection was based on linear scale relations and a specific weight of 165 lb/cu ft for the prototype stone. The proposed breakwater heads, however, involved the use of concrete dolos armor units. Since 1:60-scale dolos were not available, a stone armor was selected for testing that would yield approximately the same relative stability, transmission, and reflection characteristics as the dolos armor. Experience at WES indicates that the stone should be about 2.5 times larger by weight than the dolos to yield similar characteristics.

The Model and Appurtenances

The model reproduced approximately 4,600 ft of the Kauai shoreline and included the proposed harbor and bathymetry in the Pacific Ocean to an offshore depth of -40 ft[1] with a sloping transition to the wave generator pit el of -60 ft. The total area reproduced in the model was approximately 14,800 sq ft, representing about 1.9 square miles in the prototype. A general view of the model is shown in Figure 4. Vertical control for model construction was based on mean lower low water. Horizontal control was referenced to a local prototype grid system.

Model waves were generated by an 80-ft-long, unidirectional, spectral, electrohydraulic wave generator with a trapezoidal-shaped, vertical-motion plunger. Vertical motion of the plunger was controlled by a computer-generated command signal, and movement of the plunger caused a displacement of water which generated required test waves. The wave generator was mounted on retractable casters which enabled it to be positioned to generate waves from required directions.

An automated data acquisition and control system, designed and constructed at WES (Figure 5), was used to generate and transmit control signals, monitor wave generator feedback, and secure and analyze wave data at selected locations in the model. Through the use of a microvax computer, the electrical output of parallel-wire, capacitance-type wave gages, which varied with the change in water-surface elevation with respect to time, were recorded on magnetic disks. These data were then analyzed to obtain the parametric wave data.

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1 All elevations (el) cited herein are in feet referred to mean lower low water (mllw).

Figure 4. General view of model

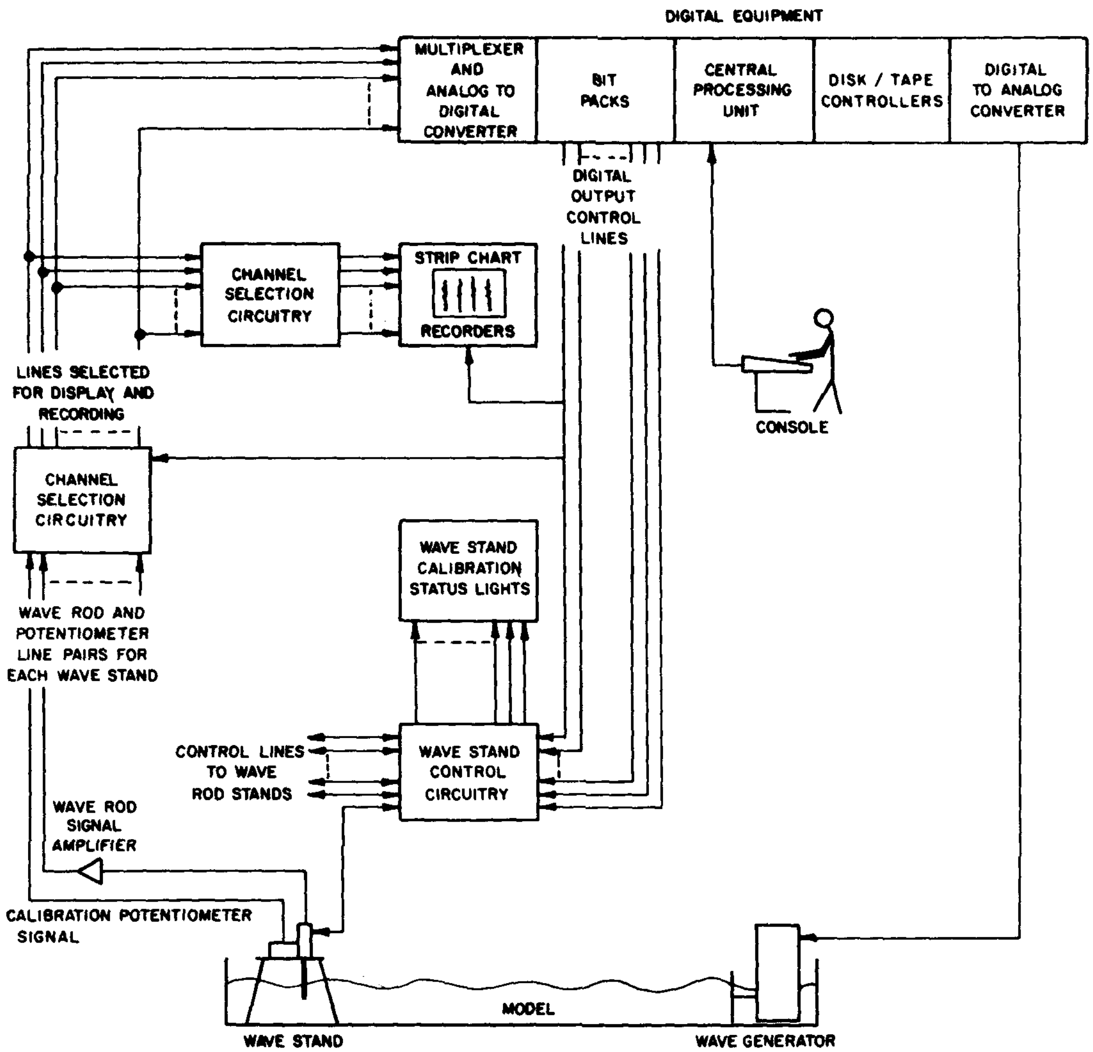

Figure 5. Automated data acquisition and control system

A 2-ft (horizontal) solid layer of fiber wave absorber was placed around the inside perimeter of the model to dampen wave energy that might otherwise be reflected from the model walls. In addition, guide vanes were placed along the wave generator sides in the flat pit area to ensure proper formation of the wave train incident to the model contours.

Selection of Tracer Material

A fixed-bed model molded in cement mortar was constructed and a tracer material selected to qualitatively determine movement and deposition of sediment in the vicinity of the harbor. The tracer was chosen in accordance with the scaling relations of Noda (1972), which indicate a relation or model law among the four basic scale ratios, i.e., the horizontal scale, λ; the vertical scale, μ; the sediment size ratio, n_D; and the relative specific weight ratio, n_γ'. These relations were determined experimentally using a wide range of wave conditions and bottom materials and are valid mainly for the breaker zone.

Noda's scaling relations indicate that movable-bed models with scales in the vicinity of 1:60 (model to prototype) should be distorted (i.e., they should have different horizontal and vertical scales). Since the fixed-bed model of Barking Sands Harbor was undistorted to allow accurate reproduction of short-period wave and current patterns, the following procedure was used to select a tracer material. Using the prototype sand characteristics (median diameter, D_{50} = 0.75 mm, specific gravity = 2.72) and assuming the horizontal scale to be in similitude (i.e. 1:60), the median diameter for a given specific gravity of tracer material and the vertical scale were computed. The vertical scale was then assumed to be in similitude and the tracer median diameter and horizontal scale were computed. This resulted in a range of tracer sizes for given specific gravities that could be used. Although several types of movable-bed tracer materials were available at WES, previous investigations (Giles and Chatham 1974, Bottin and Chatham 1975) indicated that crushed coal tracer more nearly represented movement of prototype sand. Therefore, quantities of crushed coal (specific gravity = 1.30; median diameter, D_{50} = 2.3 mm) were selected for use as a tracer material throughout the model investigation.

3 Test Conditions and Procedures

Selection of Test Conditions

Still-water level

Still-water levels (swl's) for harbor wave action models are selected so that various wave-induced phenomena that are dependent on water depths are accurately reproduced in the model. The phenomena include refraction of waves in the project area, overtopping of harbor structures by waves, reflection of wave energy from various structures, and transmission of wave energy through porous structures.

In most cases, for the following reasons, it is desirable to select a model swl that closely approximates the higher water stages which normally occur in the prototype:

a. The maximum amount of wave energy reaching a coastal area normally occurs during the higher water phase of the local tidal cycle.

b. Most storms moving onshore are characteristically accompanied by a higher water level due to wind, tide, and shoreward mass transport.

c. The selection of a high swl helps minimize model scale effects due to viscous bottom friction.

d. When a high swl is selected, a model investigation tends to yield more conservative results.

The Hawaiian Islands experience two high and two low tides daily. The tides are semidiurnal with pronounced diurnal inequalities. Tidal data representative at the site are shown below (USAED, Pacific Ocean 1985):

Tidal Data	Elevation, ft
Highest tide (estimated)	+3.0
Mean higher high water	+1.6
Mean highwater	+1.2
Half tide level	+0.7
Mean low water	+0.2
Mean lower low water	+0.0
Lowest tide (estimated)	-1.0

Swl's of +0.7 and +4.4 ft were selected by POD for use in testing the Barking Sands model. The +0.7-ft value was representative of half tide level and used while testing mean wave conditions from the various test directions. The +4.4-ft value was used while testing storm wave conditions. It consisted of mean higher high water (+1.6 ft) with an astronomical tide of 0.4 ft, a water level rise due to atmospheric pressure of 1.4 ft, a water level rise due to storm surge of 0.5 ft, and a water level rise due to wave setup of 0.5 ft superimposed.

Factors influencing selection of test wave characteristics

In planning the testing program for a model investigation of harbor wave-action problems, it is necessary to select heights, periods, and directions for the test waves that will allow a realistic test of proposed improvement plans and an accurate evaluation of the elements of the various proposals. Surface-wind waves are generated primarily by the interactions between tangential stresses of wind flowing over water, resonance between the water surface and atmospheric turbulence, and interactions between individual wave components. The height and period of the maximum significant wave that can be generated by a given storm depend on the wind speed, the length of time that wind of a given speed continues to blow, and the distance over water (fetch) that the wind blows. Selection of test wave conditions entails evaluation of such factors as:

a. Fetch and decay distances (the latter being the distance over which waves travel after leaving the generating area) for various directions from which waves can approach the problem area.

b. Frequency of occurrence and duration of storm winds from the different directions.

c. Alignment, size, and relative geographic position of the navigation entrance to the harbor.

d. Alignments, lengths, and locations of the various reflecting surfaces inside the harbor.

e. Refraction of waves caused by differentials in depth in the area seaward of the harbor, which may create either a concentration or a diffusion of wave energy at the harbor site.

Storms and wave data

Prevailing winds in the Hawaiian Islands are the northeasterly trade winds, which occur approximately 90 to 95 percent of the time during the summer months (May-October), and 55 to 65 percent of the time between November-April, with speeds of 10 to 20 mph. Storm conditions generally result when a breakdown of the trade wind circulation occurs, which is relatively infrequent.

Three classes of disturbances produce major storms in Hawaii: cold fronts, low-pressure passage, and true tropical storms or hurricanes. Cold fronts, which occur during the winter, cause spotty rainfall and gusty winds. The low-pressure passage results in heavy rain, sometimes with strong winds. A low-pressure storm type know as a "kona" storm usually occurs during the winter months and is associated with strong and persistent southerly winds and intense rainfall on the south and western side of the island of Kauai. Hurricanes, classified as storms with wind speeds *greater than* 74 mph, are infrequent, but historical records indicate that nine have passed within 200 miles of the island of Kauai.

Prototype wave data were recorded off Barking Sands from the period January 1982 to December 1984 by Scripps Institute of Oceanography (USAED, Pacific Ocean 1985). The data was obtained with a Datawell Waverider accelerometer buoy located in a water depth of 360 ft. Wave climatology for the site as a distribution of wave height in percent versus wave period is shown in the following tabulation:

Wave Period, sec	Wave Height, ft							
	0-3	3-6	6-9	9-12	12-15	15-18	>18	Total Percent
0-6.9	5.5	11.4	0.3	—	—	—	—	17.2
7.0-9.9	6.3	22.3	3.6	1.2	0.2	—	—	33.6
10.0-12.9	0.8	11.3	6.1	1.0	0.5	—	—	19.7
13.0-16.9	0.5	7.5	9.5	6.4	1.3	0.5	0.2	25.9
17.0-19.9	—	0.2	1.1	0.9	0.2	0.4	0.2	3.0
>20.0	—	0.1	0.2	0.2	0.1	—	—	0.6
Total Percent	13.1	52.8	20.8	9.7	2.3	0.9	0.4	100

Waves of 12 ft or less were recorded 96.4 percent of the time, and the largest wave recorded was 22 ft with a period of 13 sec.

Measured prototype wave data covering a sufficiently long duration from which to base a comprehensive statistical analysis of deepwater wave conditions for the Barking Sands area were not available. However, statistical wave hindcast estimates representative of this area were obtained from the WES Wave Information Studies (WIS). More information on WIS may be obtained from Corson (1985). An existing WIS computer program was modified to determine deepwater wave conditions at the site from different regions as desired. The sheltering effect of Niihau Island, west-southwest of Kauai, was also simulated. Estimated deepwater wave conditions approaching the proposed Barking Sands Harbor site, based on WIS, are presented in Table 1. These data indicated that the majority of waves approach Barking Sands from the northwest direction. The WIS data do not include waves generated by hurricanes.

Wave refraction

When waves move into water of gradually decreasing depth, transformations take place in all wave characteristics except wave period (to the first order of approximation). The most important transformations with respect to the selection of test wave characteristics are the changes in wave height and direction of travel due to the phenomenon referred to as "wave refraction." When the refraction coefficient (K_r) is determined, it is multiplied by the shoaling coefficient (K_s) and gives a conversion factor of deepwater wave heights to shallow-water values. The shoaling coefficient, a function of wave length and water depth, can be obtained from the *Shore Protection Manual* (1984). The change in wave height and direction may be determined by using the numerical Regional Coastal Processes Wave Transformation Model (RCPWAVE) developed by Ebersole (1985).

Due to the conceptual nature of the harbor configuration and limited funds for the Barking Sands project, a wave refraction analysis was not conducted. Instead, a wide range of wave conditions was tested. Changes in wave height and direction, as a result of refraction, should be covered in the bracket of wave conditions tested. Waves were generated in the -60-ft model pit. From this point, the model contours refracted the wave trains to the shore. Critical directions of wave approach were determined to be northwest, west-northwest, west, west-southwest, and southwest.

Selection of test waves

Based on the prototype wave data discussed previously herein and the WIS hindcast data (Table 1), POD selected the following test wave characteristics to be used in the model investigation.

Selected Test Waves[1]			
Direction	**Period, sec**	**Height, ft**	**swl, ft**
NW	5	6	+4.4
	7	6, 10, 13	
	9	6, 10, 13, 16, 19	
	11	6, 10, 13, 16, 19	
	13	6, 10, 13, 16, 19	
	15	6, 10, 13, 16	
	17	6, 10, 13	
	19	6, 10	
	10.3	6.9	+0.7
WNW	5	6	+4.4
	7	6, 10, 13	
	9	6, 10, 13, 16, 19	
	11	6, 10, 13, 16, 19	
	13	6, 10, 13, 16, 19	
	15	6, 10, 13, 16	
	17	6, 10, 13	
	9.7	5.9	+0.7
W	5	6, 13	+4.4
	7	6, 10, 13, 16	
	9	10, 13, 16, 19, 22	
	11	13, 19	
	7.1	8.5	+0.7
WSW	5	6, 13	+4.4
	7	6, 10, 13, 16	
	9	10, 13, 16, 19	
	7	8.9	+0.7
SW	5	6, 10	+4.4
	7	6, 10, 13, 16	
	9	13, 16, 19, 22	
	11	23	
	6.8	8.2	+0.7

[1] Wave conditions generated in -60-ft wave generator pit.

Table 1
Estimated Magnitude of Deepwater Waves (sea and swell) Approaching Barking Sands from the Directions Indicated

Wave Height, ft	Occurrences[1] per Wave Period, sec								
	4.4-6.0	6.1-8.0	8.1-10.5	10.6-11.7	11.8-13.3	13.4-15.3	15.4-18.1	18.2-22.2	Total
North-Northwest									
0.0-3.3	2	405	456	12	6	1	—	—	882
3.3-6.6	9	259	2,139	515	278	13	—	9	3,222
6.6-9.8	—	8	291	476	446	65	1	—	1,287
9.8-13.1	—	1	37	72	178	96	6	8	398
13.1-16.4	—	1	3	20	31	36	13	1	105
16.4-19.7	—	—	—	2	12	15	—	—	29
19.7-23.0	—	—	—	—	2	3	—	—	5
Total	11	674	2,926	1,097	953	229	20	18	5,928
Northwest									
0.0-3.3	8	1,148	1,275	6	47	10	27	—	2,521
3.3-6.6	13	846	9,949	2,208	677	211	82	11	13,997
6.6-9.8	—	29	1,256	3,551	3,466	751	76	1	9,130
9.8-13.1	—	3	84	427	2,483	1,280	57	1	4,335
13.1-16.4	—	—	17	56	417	640	113	—	1,243
16.4-19.7	—	—	1	4	78	209	76	—	368
19.7-23.0	—	—	—	—	8	20	38	—	66
23.0-26.2	—	—	—	—	—	—	6	—	6
Total	21	2,026	12,582	6,252	7,176	3,121	475	13	31,666

(Sheet 1 of 4)

[1] Occurrences compiled for period 1956-1975. Each occurrence represents a 3-hr duration.

Table 1 (Continued)

Wave Height, ft	Occurrences per Wave Period, sec								
	4.4-6.0	6.1-8.0	8.1-10.5	10.6-11.7	11.8-13.3	13.4-15.3	15.4-18.1	18.2-22.2	Total
West-Northwest									
0.0-3.3	13	495	1,523	30	29	19	4	—	2,113
3.3-6.6	3	133	3,311	572	185	70	46	—	4,320
6.6-9.8	—	8	153	585	803	65	6	—	1,620
9.8-13.1	—	3	26	205	598	145	5	—	982
13.1-16.4	—	—	8	38	221	99	11	—	377
16.4-19.7	—	—	13	8	53	33	1	—	108
19.7-23.0	—	—	—	—	1	17	—	—	18
Total	16	639	5,034	1,438	1,890	448	73	—	9,538
West									
0.0-3.3	31	3	—	—	—	—	—	—	34
3.3-6.6	13	9	—	—	—	—	—	—	22
6.6-9.8	—	26	29	—	—	—	—	—	55
9.8-13.1	—	17	17	1	—	—	—	—	35
13.1-16.4	2	3	10	—	—	—	—	—	15
16.4-19.7	—	—	9	1	—	—	—	—	10
19.7-23.0	—	—	3	—	—	—	—	—	3
Total	46	58	68	2	—	—	—	—	174

(Sheet 2 of 4)

Table 1 (Continued)

Wave Height, ft	Occurrences per Wave Period, sec								
	4.4-6.0	6.1-8.0	8.1-10.5	10.6-11.7	11.8-13.3	13.4-15.3	15.4-18.1	18.2-22.2	Total
West-Southwest									
0.0-3.3	20	8	—	—	—	—	—	—	28
3.3-6.6	6	15	—	—	—	—	—	—	21
6.6-9.8	—	36	2	—	—	—	—	—	38
9.8-13.1	1	17	9	—	—	—	—	—	27
13.1-16.4	—	6	19	—	—	—	—	—	25
16.4-19.7	—	—	8	—	—	—	—	—	8
Total	27	82	38	—	—	—	—	—	147
Southwest									
0.0-3.3	41	1	—	—	—	—	—	—	42
3.3-6.6	22	24	1	—	—	—	—	—	47
6.6-9.8	1	29	—	—	—	—	—	—	30
9.8-13.1	—	12	12	—	—	—	—	—	24
13.1-16.4	—	1	12	—	—	—	—	—	13
16.4-19.7	—	—	14	—	—	—	—	—	14
19.7-23.0	—	—	6	3	—	—	—	—	9
Total	64	67	45	3	—	—	—	—	179

(Sheet 3 of 4)

Table 1 (Concluded)

Wave Height, ft	Occurrences per Wave Period, sec								
	4.4-6.0	6.1-8.0	8.1-10.5	10.6-11.7	11.8-13.3	13.4-15.3	15.4-18.1	18.2-22.2	Total
South-Southwest									
0.0-3.3	20	—	—	—	—	—	—	—	20
3.3-6.6	33	4	16	—	—	—	—	—	53
6.6-9.8	6	25	—	—	—	—	—	—	31
9.8-13.1	—	16	1	—	—	—	—	—	17
13.1-16.4	—	2	5	—	—	—	—	—	7
16.4-19.7	—	—	2	—	—	—	—	—	2
Total	59	47	24	—	—	—	—	—	130

(Sheet 4 of 4)

Unidirectional wave spectra were generated (based on Joint North Sea Wave Project (JONSWAP) parameters) for most of the selected test waves and used throughout the model investigation. Plots of typical wave spectra are shown in Figure 6. The solid line represents the desired spectra while the dashed line represents the spectra reproduced in the model. A typical wave time series is shown in Figure 7, which depicts water surface elevation (η) versus time. Selected test waves were significant wave heights, the average height of the highest one-third of the waves or H_s. In deep water H_s is very similar to H_{mo} (energy based wave) where $H_{mo} = 4\,(E)^{1/2}$, and E equals total energy in the spectra which is obtained by integrating the energy density spectra over the frequency range. Due to mechanical limitations of the wave generator, monochromatic wave conditions were used to reproduce 5-sec, 13-ft waves; 9-sec, 19- and 22-ft waves; 11-sec, 19- and 22-ft waves; 13-sec, 16- and 19-ft waves; 15-sec, 13- and 16-ft waves; 17-sec, 6-, 10-, and 13-ft waves; and 19-sec, 6- and 10-ft waves.

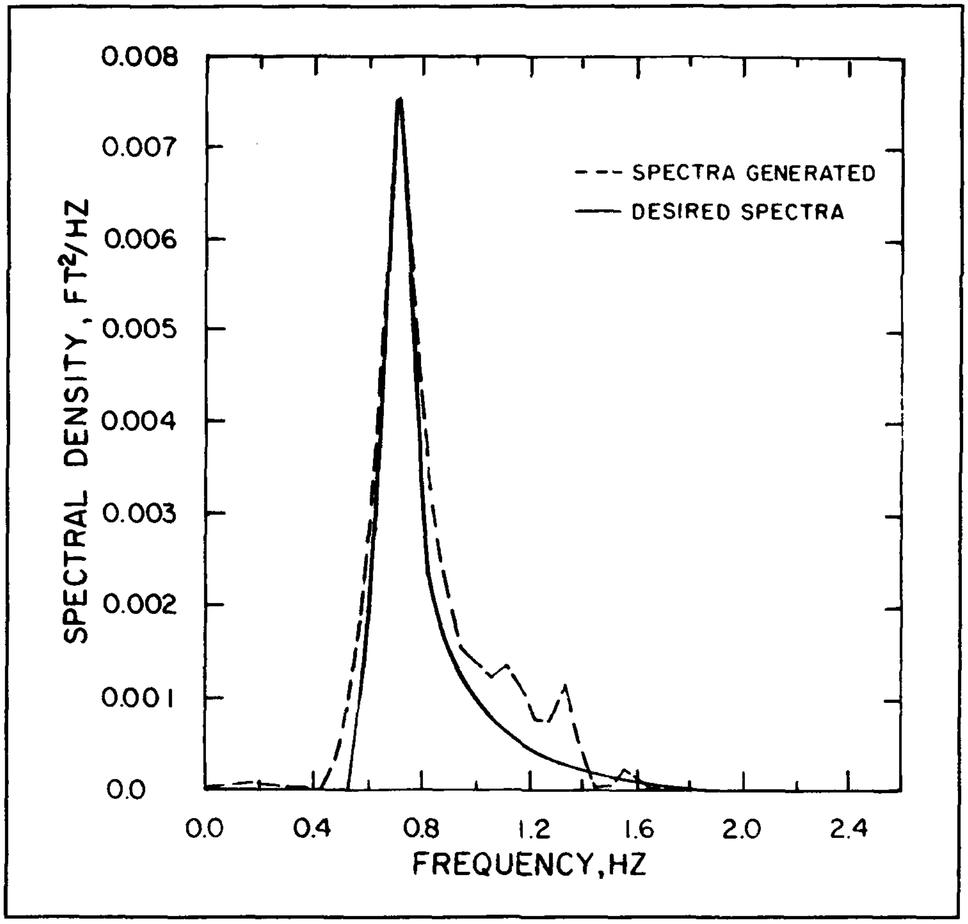

Figure 6. Typical energy density versus frequency plots (model terms) for a wave spectra; 11-sec, 10-ft test waves

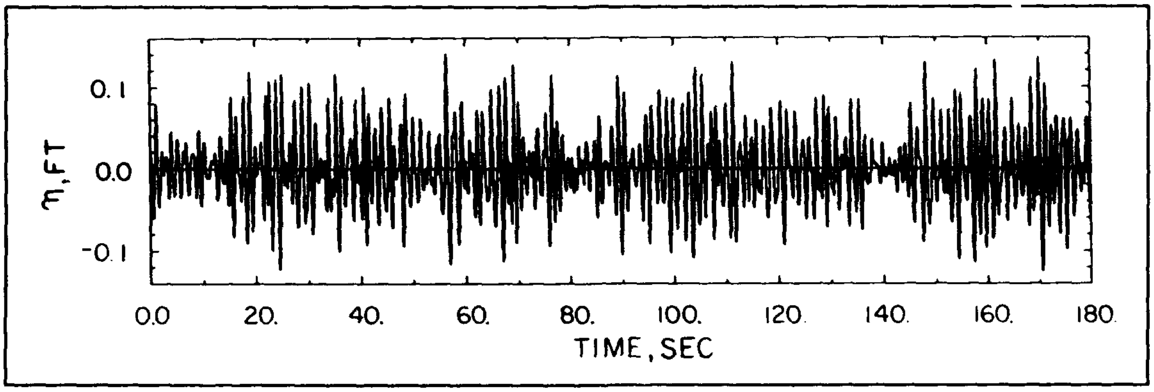

Figure 7. Typical wave train; 11-sec, 10-ft waves

Analysis of Model Data

Relative merits of the various plans tested were evaluated by:

a. Comparison of wave heights at selected locations in the model.

b. Comparison of sediment tracer movement and subsequent deposits.

c. Visual observations and wave pattern photographs.

In the wave-height data analysis, the average height of the highest one-third of the waves (H_s), recorded at each gage location, was computed. Wave heights analyzed included energy in the 0.26- to 1.55-Hz frequency band (approximately 5- to 30-sec prototype) of the wave spectra. All wave heights then were adjusted by application of Keulegan's equation[1] to compensate for excessive model wave height attenuation due to viscous bottom friction. From this equation, reduction of model wave heights (relative to the prototype) can be calculated as a function of water depth, width of wave front, wave period, water viscosity, and distance of wave travel and the model data can be corrected and converted to their prototype equivalents.

[1] G. H. Keulegan. (1950). "The gradual damping of a progressive oscillatory wave with distance in a prismatic rectangular channel," unpublished data, National Bureau of Standards, Washington, DC, prepared at request of Director, WES, Vicksburg, MS, by letter of 2 May 1950.

4 Tests and Results

The Tests

Test plans

Comprehensive tests were initially conducted for the proposed harbor basin and entrance channel with no structures installed. These tests established a base from which to evaluate the effectiveness of the various structural alternatives. Wave height tests, wave pattern photographs, and sediment tracer tests were secured for test waves from all five test directions. Brief descriptions of the test plans are presented in the following subparagraphs; dimensional details are presented in Plates 1-3.

a. Plan 1 (Plate 1) consisted of the proposed harbor basin and entrance channel with no structures installed. The plan entailed a 200-ft-wide, 20-ft-deep entrance channel extending from the basin entrance to the -20-ft contour in the Pacific Ocean and a -18-ft-deep harbor basin. The basin was approximately 450 ft by 650 ft in size and was revetted on three sides.

b. Plan 2 (Plate 2) included the harbor basin and entrance channel of Plan 1 with an 800-ft-long offshore breakwater installed approximately 1,000 ft seaward of the shoreline. The breakwater heads were constructed with stone representing 25-ton dolos armor units with a 23-ft-wide crest installed on slopes of 1V:2H while the trunk entailed 17-ton armor stone with a 20-ft-wide crest and side slopes of 1V:1.5H. The entire structure had a +24-ft crest el.

c. Plan 3 (Plate 3) entailed the harbor basin and entrance channel of Plan 1 with dual shore-connected breakwaters. The north breakwater was 1,200 ft in length and the south structure was 1,100 ft long. The heads of the structures were constructed with stone representative of 25-ton dolos armor units, and the trunks consisted of 17-ton armor stone. The breakwater head and trunk side slopes were 1V:2H and 1V:1.5H, respectively. The seaward 200-ft-long portions of the structures had crest els of +24 ft and were 23 ft in width while the remaining portions of the structures had 20-ft-wide crest widths with +20-ft crest els.

Wave height tests and wave patterns

Wave height tests and representative wave patterns for the various improvement plans were obtained for test waves from one or more of the selected test directions. Tests involving the offshore breakwater plan (Plan 2) were limited to the predominant direction of wave approach (i.e. northwest). The dual shore-connected breakwater plan of improvement (Plan 3) was tested comprehensively for waves from all test directions. Wave gage locations for each improvement plan are shown in Plates 1-3.

Sediment tracer tests

Sediment tracer tests were conducted for representative test waves from one or more of the selected test directions. Tests involving the offshore breakwater were limited to the predominant direction; however, the most promising plan (Plan 3) was tested comprehensively for representative waves from all directions. Tracer material was introduced into the model north and south of the entrance to represent sediment from those shorelines, respectively.

Test Results

Model wave heights (significant wave height or H_s) were tabulated to show measured values at selected locations. General movement of tracer material and subsequent deposits are shown in photographs. Arrows were superimposed onto photographs to define sediment movement patterns.

Test plans

Results of wave height tests conducted for Plan 1 are presented in Table 2. For test waves from the northwest, maximum wave heights[1] were 7.9 ft in the harbor entrance (gage 4) for 9-sec, 19-ft test waves and 4.0 ft in the berthing area (gage 9) for 17-sec, 6-ft test waves. Gages 9-11 are representative of the berthing area. Test waves from the west-northwest yielded maximum wave heights of 8.7 ft in the entrance for 9-sec, 19-ft test waves and 3.6 ft in the berthing area for 17-sec, 10-ft test waves. For waves from the west, maximum wave heights were 7.5 ft in the

[1] Refers to maximum significant wave heights throughout the report.

Table 2
Wave Heights for Plan 1

Test Wave			Wave Height, ft, at Indicated Gage Location													
Direction	Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14
swl = +4.4 ft																
NW	5	6	4.6	5.0	4.2	4.4	2.5	2.1	0.6	0.4	0.4	0.4	0.4	0.5	1.3	2.5
	7	6	4.4	5.3	5.0	5.5	3.5	2.7	1.3	1.4	0.7	0.8	0.6	1.5	2.4	2.1
		10	7.8	7.5	7.2	6.3	4.0	3.1	1.8	1.8	0.9	0.9	0.8	2.0	2.7	2.3
		13	10.0	9.4	7.6	6.4	4.1	3.1	1.7	1.7	1.0	0.9	1.0	1.9	2.8	2.4
	9	6	4.0	5.1	5.2	6.0	3.2	2.3	1.6	2.0	1.1	0.8	0.9	1.4	1.9	1.6
		10	7.6	8.2	7.1	6.5	3.7	2.8	1.7	2.0	1.5	0.9	1.1	1.6	2.2	2.3
		13	11.3	9.1	7.2	6.5	3.7	2.8	1.6	1.9	1.6	1.1	1.4	1.7	2.3	2.4
		16	12.5	9.7	7.7	6.6	3.8	2.8	1.7	1.9	1.7	1.1	1.3	1.7	2.3	2.5
		19	7.6	10.9	10.0	7.9	3.6	2.7	1.9	2.2	0.6	0.9	0.7	1.3	1.7	1.9
	11	6	4.1	5.1	5.8	6.1	3.4	2.4	1.5	1.9	1.4	0.9	1.1	1.4	1.9	1.9
		10	8.6	9.5	7.4	6.3	3.6	2.8	1.8	2.0	1.9	1.2	1.7	1.7	2.3	2.3
		13	12.8	9.0	7.8	6.0	3.3	2.6	1.8	2.0	2.2	1.3	1.8	1.6	2.0	2.2
		16	11.9	9.4	7.8	6.2	3.7	2.9	1.9	2.1	2.5	1.2	2.0	1.8	2.1	2.4
		19	11.1	7.1	6.4	7.7	3.3	2.7	1.6	2.4	0.7	0.7	1.1	1.4	1.9	2.6
	13	6	4.3	5.1	5.5	5.4	3.1	2.3	1.5	1.9	1.7	1.2	1.5	1.4	1.8	1.8
		10	10.0	9.8	6.7	5.8	3.3	2.7	1.7	2.0	2.1	1.3	1.9	1.6	2.0	2.2
		13	12.0	9.0	6.8	6.0	3.7	2.8	1.8	2.2	2.4	1.3	2.1	1.9	2.2	2.4
		16	14.0	8.8	6.8	6.2	4.0	3.4	1.4	0.9	0.8	1.1	0.9	1.4	2.4	2.5
		19	12.0	10.0	7.2	6.5	4.1	3.6	1.5	1.0	0.8	1.1	0.9	1.6	2.6	2.7

(Sheet 1 of 5)

Table 2 (Continued)

Test Wave			Wave Height, ft, at Indicated Gage Location													
Direction	Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14
swl = +4.4 ft (Continued)																
NW	15	6	5.8	6.7	6.5	5.6	3.3	2.5	1.8	2.2	2.1	1.5	1.9	1.6	2.0	2.0
		10	11.5	9.7	6.8	5.7	3.2	2.5	1.8	2.0	2.2	1.4	2.1	1.5	2.0	2.2
		13	11.4	9.3	5.4	5.6	3.3	2.4	1.7	1.7	0.9	1.3	0.8	1.6	2.6	1.8
		16	11.3	9.4	5.4	6.3	4.0	2.9	1.9	1.9	1.0	1.3	1.0	1.7	2.8	2.1
	17	6	8.2	7.6	9.1	6.6	5.5	3.4	1.1	4.2	4.0	2.7	3.4	2.0	2.0	1.9
		10	15.4	11.8	8.7	6.6	4.8	3.1	1.3	3.9	3.4	2.5	3.2	1.9	2.2	1.8
		13	16.4	11.2	8.1	6.5	4.5	3.1	1.5	3.9	3.3	2.3	2.7	2.0	2.1	1.9
	19	6	8.6	9.9	8.5	5.4	2.6	2.7	3.7	2.6	2.0	1.3	2.6	2.2	2.5	1.7
		10	12.8	8.9	6.6	6.6	4.3	3.7	2.6	1.7	1.3	1.4	1.8	1.6	2.5	2.8
WNW	5	6	5.5	4.8	3.7	3.2	2.5	1.9	0.5	0.3	0.3	0.2	0.3	0.5	1.1	2.0
	7	6	6.3	5.4	4.0	3.5	2.6	1.8	0.8	0.7	0.4	0.3	0.5	0.9	1.5	1.6
		10	8.8	8.2	7.2	6.5	4.2	3.3	1.6	1.6	1.0	0.6	0.9	1.7	2.8	2.7
		13	10.4	9.9	8.5	7.9	5.1	4.0	2.0	2.0	1.4	0.8	1.2	2.2	3.4	3.3
	9	6	6.5	5.4	3.5	3.2	1.9	1.3	0.7	0.9	0.6	0.3	0.5	0.7	1.0	1.2
		10	9.3	8.4	7.6	7.0	4.0	3.0	1.8	2.0	1.6	0.9	1.3	1.7	2.4	2.5
		13	10.4	9.8	8.2	7.2	4.2	3.2	1.9	2.2	2.2	1.2	1.6	1.9	2.6	2.8
		16	11.8	11.1	8.7	7.3	4.4	3.3	2.1	2.4	2.4	1.3	2.1	2.2	2.8	2.8
		19	8.9	12.5	9.9	8.7	4.1	2.4	2.6	3.0	0.8	0.8	0.8	1.5	1.6	1.9

(Sheet 2 of 5)

Table 2 (Continued)

Test Wave			Wave Height, ft, at Indicated Gage Location													
Direction	Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14
swl = +4.4 ft (Continued)																
WNW	11	6	6.8	5.4	3.8	3.8	2.1	1.6	0.9	1.3	1.1	0.6	0.9	1.0	1.2	1.3
		10	10.3	8.9	8.3	6.9	4.0	3.0	2.0	2.4	2.2	1.1	1.8	1.9	2.4	2.3
		13	11.2	10.8	8.8	7.1	4.2	3.2	2.2	2.5	2.4	1.3	2.0	2.1	2.6	2.6
		16	12.0	11.3	8.5	7.1	4.5	3.3	2.3	2.4	2.5	1.6	2.2	2.2	2.7	2.8
		19	11.8	10.7	8.2	7.1	3.0	2.2	1.4	2.1	0.5	0.5	0.9	1.3	1.8	2.3
	13	6	7.2	5.8	4.0	3.5	2.3	1.6	1.4	1.7	1.5	1.1	1.2	1.1	1.3	1.4
		10	9.8	9.7	8.6	6.1	4.0	3.0	2.2	2.6	2.7	1.6	2.2	2.0	2.4	2.6
		13	11.0	11.3	8.3	6.6	4.3	3.3	2.2	2.6	2.8	1.6	2.2	2.2	2.6	2.6
		16	12.8	11.6	7.9	6.3	4.4	3.7	1.4	1.1	1.1	1.2	1.0	1.5	2.7	2.7
		19	12.6	12.0	6.5	5.8	3.8	3.3	1.3	1.1	1.0	1.1	1.0	1.4	2.4	2.4
	15	6	7.6	6.3	4.6	4.2	2.8	2.2	1.7	2.3	2.0	1.4	1.7	1.5	1.6	1.8
		10	11.6	11.0	9.2	6.8	4.2	3.2	2.4	2.9	2.6	1.7	2.4	2.0	2.5	2.8
		13	14.0	15.2	8.9	5.6	3.9	3.0	2.4	2.3	1.3	1.6	1.1	2.3	2.9	1.9
		16	13.7	12.2	7.7	5.8	4.1	3.1	2.3	2.3	1.3	1.6	1.2	2.3	3.0	2.0
	17	6	10.4	8.8	6.6	4.6	4.8	4.0	2.2	4.9	3.5	3.5	3.0	1.8	1.9	2.3
		10	12.8	13.7	10.9	6.9	4.9	4.0	1.3	4.4	3.6	2.8	3.2	2.0	2.2	2.6
		13	14.2	12.8	11.5	6.4	5.0	3.5	1.4	4.2	3.0	2.4	2.8	2.0	2.4	2.3
West	5	6	5.5	5.4	4.7	3.6	2.6	2.1	0.8	0.5	0.4	0.2	0.6	0.8	1.3	1.6
		13	9.9	11.8	8.8	7.5	5.1	3.7	1.9	1.1	0.6	1.2	1.8	1.7	2.0	3.2

(Sheet 3 of 5)

Table 2 (Continued)

Test Wave			Wave Height, ft, at Indicated Gage Location													
Direction	Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14
swl = +4.4 ft (Continued)																
West	7	6	6.6	6.5	4.4	2.7	2.0	1.6	0.8	0.7	0.5	0.3	0.5	0.9	1.3	1.1
		10	10.2	9.9	7.2	5.0	3.5	2.7	1.4	1.4	1.1	0.8	1.0	1.5	2.2	1.9
		13	11.2	10.7	8.5	5.9	4.1	3.4	1.7	1.7	1.4	0.9	1.5	1.7	2.8	2.4
		16	12.4	11.2	8.6	6.5	4.4	3.3	1.7	1.9	1.7	1.1	1.5	1.8	2.8	2.6
	9	10	10.8	10.0	7.3	5.3	3.1	2.3	1.5	1.8	1.8	1.3	1.5	1.5	2.0	1.8
		13	11.5	11.0	8.6	5.9	3.6	2.8	2.0	2.2	2.5	1.6	2.2	2.1	2.2	2.2
		16	11.6	11.3	8.1	6.3	4.1	3.1	2.3	2.3	2.9	1.8	2.3	2.3	2.7	2.8
		19	11.9	11.6	7.1	6.5	2.9	1.9	1.8	1.8	0.7	0.7	0.7	1.2	1.4	1.3
		22	11.0	10.6	7.0	6.6	3.1	2.3	2.0	2.0	0.7	0.7	0.6	1.3	1.4	1.4
	11	13	12.9	13.1	9.4	6.3	4.1	3.2	2.5	3.0	3.3	2.1	3.0	2.5	2.6	2.6
		19	13.7	12.6	9.3	5.9	2.9	2.3	1.7	1.9	0.7	0.5	1.4	1.5	1.8	1.9
WSW	5	6	5.0	5.1	3.7	2.7	2.1	1.8	0.6	0.4	0.4	0.2	0.4	0.7	1.1	1.3
		13	10.4	11.2	7.6	7.0	5.2	3.7	1.7	0.9	0.5	1.1	1.4	1.5	1.9	3.0
	7	6	6.2	5.7	3.7	2.7	2.0	1.6	0.8	0.7	0.5	0.3	0.6	1.0	1.4	1.1
		10	9.5	9.4	6.2	5.3	3.4	2.7	1.6	1.4	1.2	0.7	1.1	1.7	2.3	1.9
		13	12.1	11.6	7.3	6.6	4.0	3.2	1.9	1.7	1.4	0.8	1.5	2.0	2.7	2.2
		16	12.9	11.8	8.3	7.2	4.7	3.7	2.3	2.2	1.9	1.1	2.0	2.4	3.2	2.5
	9	10	10.6	9.6	6.8	5.3	3.3	2.5	1.8	1.8	1.9	1.1	1.5	1.7	2.1	1.8
		13	13.5	12.9	8.4	6.6	3.7	2.9	2.3	2.2	2.2	1.3	2.0	2.1	2.7	2.3

(Sheet 4 of 5)

Table 2 (Concluded)

Test Wave			Wave Height, ft, at Indicated Gage Location													
Direction	Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14
swl = +4.4 ft (Concluded)																
WSW		16	13.8	12.8	8.1	6.5	3.8	3.0	2.5	2.5	2.7	1.5	2.4	2.3	2.5	2.6
		19	14.7	13.1	9.0	9.4	5.3	3.6	2.9	2.5	1.0	0.8	1.1	2.5	2.9	2.1
SW	5	6	4.9	4.7	3.3	4.2	3.2	2.6	1.5	0.7	0.6	0.4	1.1	1.5	1.9	1.8
		10	8.4	7.7	5.8	6.1	4.3	3.3	1.9	1.2	1.2	0.7	1.7	1.9	2.7	2.8
	7	6	5.5	5.3	4.5	4.7	3.3	2.5	1.6	1.4	0.9	0.5	1.0	1.8	2.5	1.7
		10	9.8	9.2	6.2	6.2	4.2	3.1	2.2	2.0	1.3	0.8	1.5	2.2	3.0	2.2
		13	11.0	9.0	6.4	6.7	4.3	3.1	2.3	2.2	1.8	1.1	2.0	2.2	3.1	2.5
		16	11.6	9.9	7.0	7.0	4.5	3.5	2.5	2.5	2.2	1.4	2.5	2.5	3.1	2.9
	9	13	11.5	10.3	7.1	6.9	4.1	3.0	2.6	2.6	2.4	1.5	2.5	2.4	2.8	2.3
		16	12.6	10.6	7.8	7.7	4.7	3.5	2.8	2.9	2.8	1.8	3.0	2.8	3.3	2.9
		19	13.3	9.5	7.4	7.7	5.3	3.8	3.3	2.2	1.1	1.0	1.2	3.4	3.6	2.1
		23	12.0	10.9	7.7	7.8	5.3	3.5	3.2	2.4	1.2	0.6	1.2	3.1	3.1	2.1
	11	23	11.1	10.2	10.8	8.2	4.8	3.4	2.6	2.8	1.1	0.7	2.7	2.5	2.3	3.2
swl = +0.7 ft																
NW	10.3	6.9	4.1	5.9	5.0	4.2	2.5	1.9	1.0	1.1	1.1	0.7	0.7	1.0	1.5	1.7
WNW	9.7	5.9	6.6	5.4	3.5	3.2	1.8	1.3	0.7	1.0	1.2	0.6	1.0	0.8	1.0	1.2
West	7.1	8.5	9.0	8.4	5.4	3.5	2.5	2.0	1.1	0.9	0.8	0.5	0.7	1.0	1.6	1.4
WSW	7.0	8.9	8.3	8.3	5.0	3.3	2.2	1.8	1.0	0.9	1.2	0.7	1.0	1.0	1.4	1.3
SW	6.8	8.2	8.7	8.3	5.2	4.4	3.0	2.3	1.5	1.2	1.0	0.5	1.0	1.5	2.1	1.6

(Sheet 5 of 5)

entrance for 5-sec, 13-ft test waves and 3.3 ft in the berthing area for 11-sec, 13-ft test waves. Waves from the west-southwest resulted in maximum wave heights of 9.4 ft in the entrance for 9-sec, 19-ft test waves and 2.7 ft in the berthing area for 9-sec, 16-ft test waves. For waves from the southwest, maximum wave heights were 8.2 ft in the entrance for 11-sec, 23-ft test waves and 3.0 ft in the berthing area for 9-sec, 16-ft test waves. For mean wave conditions from the various directions with the +0.7-ft swl, maximum wave heights in the entrance were 4.4 ft for 6.8-sec, 8.2-ft test waves from southwest and 1.2 ft in the berthing area for 9.7-sec, 5.9-ft test waves from west-northwest and 7-sec, 8.9-ft test waves from the west-southwest. Typical wave patterns obtained for Plan 1 are shown in Photos 1-15.

The general movement of tracer material and subsequent deposits obtained for Plan 1 are shown in Photos 16-30 for representative test waves from the five selected directions. For waves from the northwest and west-northwest, sediment tracer on the shoreline north of the harbor moved southerly and deposited in the entrance channel. Waves from the west, west-southwest, and southwest caused tracer material on the shoreline south of the harbor to move northerly and deposit in the entrance channel.

Wave height test results with Plan 2 installed are presented in Table 3 for test waves from northwest. Maximum wave heights were 8.7 ft in the harbor basin entrance (gage 4) for 9-sec, 19-ft test waves and 3.1 ft in the berthing area (gage 9) for 17-sec, 13-ft test waves. For mean wave conditions (6.9-ft incident waves) with the +0.7-ft swl, maximum wave heights were 3.5 ft in the basin entrance and 0.9 ft in the berthing area (gage 9). Typical wave patterns obtained for Plan 2 are shown in Photos 31-33.

The general movement of tracer material and subsequent deposits for Plan 2 are shown in Photos 34-36 for test waves from the northwest. Sediment tracer material on the shoreline north of the harbor migrated southerly and deposited in the entrance channel for all waves tested.

Results of wave height tests conducted for Plan 3 are presented in Table 4. For test waves from the northwest, maximum wave heights were 1.4 ft in the harbor basin entrance (gage 4) for 9-sec, 19-ft test waves and 1.0 ft in the berthing area for 11-sec, 16-ft and 13-sec, 13-ft test waves. Test waves from the west-northwest resulted in maximum wave heights of 1.5 ft in the basin entrance for 9-sec, 19-ft and 15-sec, 13- and 16-ft test waves and 1.3 ft in the berthing area for 11-sec, 16-ft test waves. For waves from the west, maximum wave heights were 2.2 ft in the basin entrance for 5-sec, 13-ft test waves and 1.6 ft in the berthing area for 11-sec, 13-ft test waves. Test waves from the west-southwest yielded maximum wave heights of 2.6 ft in the basin entrance for 5-sec, 13-ft test waves and 1.6 ft in the berthing area for 9-sec, 16-ft test waves. For waves from the southwest, maximum wave heights were 1.8 ft in the basin entrance for 9-sec, 19-ft test waves and 1.5 ft in the berthing area for 9-sec, 16-ft test waves. For mean wave conditions from the various directions with the +0.7-ft swl, maximum wave heights were 1.3 ft and 0.5 ft in the basin

Table 3
Wave Heights for Plan 2 for Test Waves from the Northwest

Test Wave		Wave Height, ft, at Indicated Gage Location													
Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14
swl = +4.4 ft															
5	6	1.0	2.0	3.6	3.7	2.1	1.8	0.6	0.4	0.3	0.5	0.5	0.4	0.9	2.2
7	6	1.2	2.1	4.1	4.4	2.9	2.1	1.2	0.9	0.6	0.6	0.6	1.1	1.9	1.9
	10	1.6	3.4	6.1	5.3	3.4	2.4	1.6	1.2	0.8	0.7	0.7	1.5	2.2	2.1
	13	2.3	4.9	6.7	5.6	3.5	2.5	1.6	1.3	0.8	0.8	0.7	1.5	2.1	2.2
9	6	1.4	2.3	4.5	4.6	2.5	1.7	1.1	1.3	0.9	0.6	0.6	0.9	1.3	1.5
	10	2.1	4.3	6.6	5.4	3.1	2.2	1.3	1.3	1.3	0.8	1.0	1.2	1.7	2.1
	13	2.8	5.5	6.5	5.6	3.2	2.4	1.4	1.4	1.4	0.9	1.1	1.3	1.9	2.2
	16	3.3	6.0	6.8	5.7	3.3	2.4	1.4	1.5	1.5	1.0	1.1	1.4	1.9	2.2
	19	4.0	8.5	8.5	8.7	4.1	3.0	1.9	1.7	0.8	0.9	0.7	1.1	1.8	2.2
11	6	1.7	2.4	5.2	4.9	2.8	1.9	1.2	1.4	1.2	0.8	0.9	1.0	1.5	1.8
	10	2.6	4.6	6.8	5.2	3.0	2.3	1.3	1.4	1.7	1.0	1.4	1.4	1.7	2.2
	13	3.2	5.2	6.7	5.2	3.1	2.3	1.5	1.7	2.1	1.1	1.6	1.4	1.8	2.1
	16	3.5	5.6	6.9	5.7	3.3	2.5	1.7	2.0	2.2	1.2	1.6	1.6	1.9	2.3
	19	3.5	5.3	5.2	6.2	2.9	2.1	1.0	1.6	0.5	0.6	0.6	1.2	1.6	2.5
13	6	1.8	2.7	4.4	4.3	2.4	1.7	1.2	1.4	1.5	1.0	1.1	1.1	1.3	1.6
	10	3.0	4.9	6.3	5.7	3.2	2.3	1.7	1.8	2.1	1.3	1.7	1.4	1.9	2.2
	13	3.7	5.8	6.7	5.5	3.2	2.4	1.6	1.8	2.0	1.1	1.4	1.4	1.9	2.2
	16	2.7	3.7	4.5	4.6	2.7	2.0	0.8	0.4	0.7	0.8	0.6	0.9	1.6	1.8
	19	4.0	5.8	7.3	5.5	4.0	3.3	1.3	0.8	1.1	1.3	0.9	1.5	2.6	2.6

(Continued)

Table 3 (Concluded)

Test Wave		Wave Height, ft, at Indicated Gage Location													
Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14
swl = +4.4 ft (Concluded)															
15	6	1.9	3.3	4.8	4.4	2.6	1.9	1.4	1.5	1.6	1.0	1.4	1.1	1.6	1.7
	10	3.1	5.3	6.1	5.0	2.9	2.2	1.5	1.7	1.8	1.2	1.6	1.3	1.8	2.0
	13	3.0	4.9	5.0	4.9	3.5	2.4	1.6	1.4	0.7	1.3	0.7	1.5	2.1	2.1
	16	3.1	4.7	5.2	5.2	3.5	2.6	1.7	1.4	0.8	1.3	0.8	1.4	2.2	2.1
17	6	3.3	4.0	7.9	4.9	3.8	2.5	1.0	3.0	2.8	2.3	2.4	1.5	1.4	1.6
	10	6.8	5.6	6.1	4.8	3.8	2.4	1.1	3.2	3.0	2.3	2.5	1.4	1.5	1.6
	13	5.6	4.7	6.0	5.3	4.4	3.3	1.2	3.3	3.1	2.3	2.5	1.6	1.7	1.8
19	6	2.9	5.3	5.2	4.1	2.5	2.0	3.0	1.7	1.7	1.0	2.0	1.3	2.6	1.7
	10	3.5	4.7	4.8	4.6	2.6	2.1	2.0	1.5	1.1	0.8	1.3	1.1	1.7	2.0
swl = +7.0 ft															
10.3	6.9	1.6	2.8	3.9	3.5	2.0	1.5	0.8	0.8	0.9	0.5	0.6	0.8	1.1	1.6

Table 4 Wave Heights for Plan 3																
Test Wave			Wave Height, ft, at Indicated Gage Location													
Direction	Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14
swl = +4.4 ft																
NW	5	6	0.6	0.4	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	7	6	1.0	0.8	0.4	0.3	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2
		10	1.7	1.3	0.8	0.6	0.4	0.2	0.2	0.1	0.2	0.1	0.2	0.2	0.3	0.3
		13	2.2	1.7	1.0	0.7	0.5	0.4	0.2	0.3	0.4	0.2	0.3	0.3	0.4	0.4
	9	6	1.4	0.8	0.5	0.3	0.2	0.2	0.1	0.1	0.2	0.1	0.2	0.1	0.2	0.2
		10	2.2	1.1	0.8	0.6	0.4	0.3	0.2	0.3	0.5	0.2	0.4	0.3	0.3	0.3
		13	2.5	1.4	1.0	0.7	0.5	0.4	0.3	0.4	0.7	0.3	0.5	0.4	0.4	0.4
		16	2.8	1.6	1.2	0.8	0.6	0.5	0.3	0.5	0.7	0.3	0.6	0.4	0.4	0.5
		19	3.7	1.8	1.6	1.4	0.8	0.6	0.3	0.2	0.2	0.2	0.1	0.3	0.6	0.4
	11	6	1.4	0.8	0.6	0.4	0.3	0.2	0.1	0.2	0.3	0.1	0.2	0.1	0.1	0.2
		10	2.0	1.1	0.9	0.6	0.4	0.3	0.2	0.3	0.6	0.3	0.5	0.3	0.3	0.4
		13	2.4	1.3	1.0	0.7	0.5	0.4	0.3	0.4	0.7	0.3	0.6	0.4	0.4	0.5
		16	2.8	1.7	1.3	0.9	0.7	0.3	0.4	0.6	1.0	0.4	0.8	0.5	0.5	0.7
		19	2.5	2.3	1.8	1.2	0.9	0.2	0.3	0.2	0.1	0.1	0.2	0.4	0.5	0.6
	13	6	1.6	1.1	0.8	0.5	0.4	0.3	0.2	0.3	0.4	0.2	0.3	0.2	0.3	0.3
		10	2.3	1.5	1.1	0.7	0.6	0.4	0.3	0.5	0.8	0.4	0.7	0.4	0.4	0.5
		13	2.5	1.6	1.2	0.8	0.6	0.4	0.4	0.6	1.0	0.4	0.8	0.5	0.5	0.6
		16	2.5	2.0	1.6	0.9	0.8	0.6	0.2	0.2	0.2	0.2	0.2	0.3	0.5	0.5
		19	2.7	2.1	1.6	0.8	0.8	0.6	0.2	0.2	0.2	0.2	0.2	0.3	0.5	0.5

(Sheet 1 of 5)

Table 4 (Continued)

Test Wave			Wave Height, ft, at Indicated Gage Location													
Direction	Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14
swl = +4.4 ft (Continued)																
NW	15	6	1.6	0.9	0.6	0.4	0.3	0.2	0.2	0.2	0.3	0.2	0.3	0.2	0.3	0.3
		10	2.4	1.6	1.0	0.7	0.6	0.4	0.3	0.5	0.8	0.3	0.7	0.4	0.4	0.5
		13	2.6	2.2	1.3	0.9	0.6	0.5	0.5	0.4	0.3	0.4	0.3	0.5	0.4	0.3
		16	2.5	2.1	1.3	0.9	0.6	0.5	0.5	0.4	0.3	0.4	0.3	0.5	0.4	0.3
	17	6	2.3	1.3	0.6	0.5	0.4	0.2	0.1	0.2	0.3	0.2	0.2	0.1	0.1	0.1
		10	2.9	1.8	1.3	0.7	0.7	0.5	0.3	0.5	0.5	0.4	0.3	0.3	0.3	0.2
		13	3.3	2.3	1.5	1.0	0.9	0.6	0.4	0.2	0.6	0.5	0.4	0.3	0.5	0.4
	19	6	2.2	1.2	0.6	0.5	0.4	0.3	0.2	0.2	0.1	0.2	0.2	0.2	0.2	0.2
		10	3.3	1.6	1.1	0.7	0.6	0.5	0.4	0.2	0.3	0.2	0.3	0.2	0.4	0.3
WNW	5	6	1.1	1.0	0.6	0.4	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2
	7	6	2.3	1.5	0.7	0.4	0.3	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2
		10	3.3	2.0	1.1	0.7	0.6	0.4	0.2	0.2	0.4	0.2	0.3	0.3	0.4	0.4
		13	3.8	2.5	1.5	0.9	0.7	0.6	0.3	0.4	0.6	0.3	0.6	0.4	0.5	0.5
	9	6	2.3	1.4	0.7	0.5	0.4	0.3	0.2	0.3	0.4	0.1	0.3	0.2	0.3	0.3
		10	3.5	2.1	1.2	0.8	0.6	0.5	0.3	0.4	0.7	0.2	0.5	0.3	0.4	0.4
		13	3.7	2.3	1.3	1.0	0.7	0.5	0.3	0.6	0.9	0.3	0.7	0.4	0.5	0.5
		16	3.8	2.7	1.6	1.1	0.8	0.6	0.4	0.6	1.1	0.4	0.9	0.5	0.6	0.7
		19	3.9	2.6	2.0	1.5	0.8	0.7	0.4	0.3	0.2	0.2	0.2	0.3	0.5	0.4

(Sheet 2 of 5)

Table 4 (Continued)

Test Wave			Wave Height, ft, at Indicated Gage Location													
Direction	Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14
swl = +4.4 ft (Continued)																
WNW	11	6	2.0	1.3	0.8	0.5	0.4	0.3	0.2	0.3	0.4	0.2	0.4	0.2	0.3	0.3
		10	2.9	1.8	1.2	0.8	0.6	0.5	0.3	0.5	0.8	0.3	0.6	0.3	0.4	0.5
		13	3.2	2.2	1.5	1.0	0.8	0.6	0.4	0.6	1.0	0.4	0.8	0.4	0.6	0.6
		16	3.7	2.6	1.8	1.2	0.9	0.7	0.5	0.7	1.3	0.5	0.9	0.5	0.7	0.8
		19	3.3	2.8	1.9	1.2	0.9	0.7	0.3	0.3	0.2	0.2	0.2	0.4	0.6	0.7
	13	6	2.4	1.8	1.1	0.7	0.5	0.4	0.3	0.4	0.6	0.4	0.5	0.4	0.4	0.4
		10	3.2	2.4	1.6	1.0	0.8	0.6	0.5	0.6	0.8	0.5	0.7	0.5	0.5	0.5
		13	3.3	2.6	1.9	1.2	0.9	0.7	0.5	0.6	0.9	0.5	0.7	0.5	0.6	0.6
		16	2.5	2.1	1.6	0.9	0.8	0.6	0.3	0.2	0.2	0.2	0.2	0.3	0.5	0.5
		19	2.4	2.1	1.6	0.9	0.8	0.6	0.3	0.2	0.3	0.2	0.2	0.3	0.5	0.5
	15	6	3.0	2.2	1.3	0.8	0.6	0.4	0.4	0.6	0.7	0.4	0.7	0.5	0.4	0.4
		10	3.7	2.9	1.9	1.2	0.9	0.6	0.5	0.7	0.9	0.6	0.8	0.6	0.6	0.6
		13	4.6	3.8	2.3	1.5	1.1	0.9	0.7	0.5	0.3	0.5	0.4	0.6	0.6	0.7
		16	4.5	4.8	2.3	1.5	1.1	0.8	0.7	0.5	0.3	0.5	0.3	0.6	0.6	0.7
	17	6	3.7	2.6	1.8	1.1	1.2	0.6	0.6	1.0	0.9	0.8	0.7	0.5	0.5	0.3
		10	4.6	3.9	3.1	1.4	1.4	0.8	0.7	1.2	1.2	1.0	0.9	0.6	0.7	0.6
		13	4.8	3.9	2.8	1.4	1.4	0.9	0.6	1.2	1.1	1.1	0.9	0.6	0.6	0.6
West	5	6	2.2	2.4	1.8	1.2	0.7	0.7	0.2	0.1	0.1	0.1	0.2	0.2	0.4	0.5
		13	4.8	5.1	3.0	2.2	1.2	1.3	0.5	0.3	0.2	0.4	0.3	0.4	0.5	1.0

(Sheet 3 of 5)

Table 4 (Continued)

Test Wave			Wave Height, ft, at Indicated Gage Location													
Direction	Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14
swl = +4.4 ft (Continued)																
West	7	6	2.7	2.3	1.5	1.0	0.6	0.6	0.3	0.2	0.3	0.2	0.2	0.3	0.5	0.5
		10	4.5	3.6	2.2	1.4	1.1	0.9	0.4	0.4	0.6	0.3	0.5	0.5	0.7	0.8
		13	5.6	4.3	2.6	1.5	1.2	1.0	0.5	0.5	0.9	0.4	0.7	0.6	0.9	0.9
		16	5.8	4.4	2.7	1.6	1.3	1.0	0.5	0.7	1.2	0.4	1.0	0.6	0.9	0.9
	9	10	4.1	3.1	1.9	1.2	0.9	0.7	0.4	0.5	0.9	0.3	0.6	0.5	0.6	0.6
		13	4.6	3.2	2.0	1.2	1.0	0.8	0.4	0.7	1.2	0.4	0.9	0.6	0.7	0.7
		16	5.1	3.5	2.2	1.4	1.1	0.8	0.5	0.9	1.5	0.6	1.2	0.7	0.8	0.9
		19	5.1	3.3	2.4	1.6	1.0	0.7	0.5	0.4	0.3	0.2	0.2	0.4	0.8	0.5
		22	5.7	3.6	2.7	1.9	1.0	0.7	0.6	0.5	0.3	0.2	0.2	0.4	0.7	0.6
	11	13	4.8	3.5	2.2	1.3	1.0	0.8	0.5	1.0	1.6	0.6	1.3	0.8	0.7	0.8
		19	4.5	4.4	3.1	1.9	1.5	1.3	0.5	0.4	0.3	0.3	0.4	0.8	1.1	1.1
WSW	5	6	4.2	3.2	2.3	1.6	1.1	0.9	0.4	0.2	0.2	0.2	0.2	0.4	0.6	0.7
		13	6.9	5.7	3.6	2.6	1.8	1.7	0.7	0.3	0.2	0.4	0.3	0.5	0.6	0.2
	7	6	3.9	2.9	1.9	1.2	1.0	0.8	0.4	0.2	0.2	0.2	0.2	0.4	0.6	0.6
		10	5.9	4.3	2.7	1.6	1.4	1.0	0.5	0.4	0.6	0.3	0.5	0.5	0.8	0.9
		13	7.1	4.9	3.0	1.7	1.5	1.1	0.5	0.6	0.8	0.4	0.7	0.6	1.0	1.0
		16	7.1	5.1	3.1	1.8	1.5	1.2	0.6	0.7	0.1	0.4	0.9	0.7	1.0	1.1

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Table 4 (Concluded)

Test Wave			Wave Height, ft, at Indicated Gage Location													
Direction	Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14
swl = +4.4 ft (Concluded)																
WSW	9	10	5.6	3.5	2.2	1.4	1.0	0.8	0.4	0.6	0.9	0.3	0.8	0.5	0.7	0.7
		13	6.7	4.1	2.7	1.7	1.3	1.0	0.5	0.9	1.4	0.5	0.1	0.7	0.9	0.9
		16	6.8	4.4	2.8	1.7	1.4	1.1	0.6	1.0	1.6	0.6	1.3	0.9	1.0	1.1
		19	5.1	3.3	2.2	1.8	1.0	0.6	0.3	0.4	0.2	0.2	0.2	0.3	0.6	0.4
SW	5	6	2.8	2.0	1.1	0.8	0.5	0.4	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.3
	7	6	2.6	1.8	0.9	0.6	0.4	0.4	0.1	0.1	0.2	0.1	0.2	0.1	0.2	0.3
		10	4.9	3.3	1.8	1.1	0.9	0.7	0.3	0.3	0.5	0.2	0.4	0.4	0.5	0.7
		13	5.9	4.0	2.3	1.3	1.1	0.9	0.4	0.4	0.6	0.3	0.5	0.5	0.7	0.8
		16	6.5	4.5	2.7	1.6	1.3	1.0	0.5	0.6	1.1	0.4	0.9	0.6	0.8	1.0
	9	13	6.2	3.9	2.4	1.6	1.2	1.0	0.5	0.7	1.2	0.4	0.9	0.7	0.8	0.9
		16	6.5	4.1	2.6	1.6	1.2	1.0	0.6	0.8	1.5	0.5	1.1	0.7	0.8	1.0
		19	5.5	3.0	2.2	1.8	0.9	0.6	0.5	0.3	0.2	0.1	0.2	0.3	0.3	0.4
		22	5.1	2.9	2.2	1.5	0.7	0.5	0.4	0.3	0.2	0.1	0.2	0.3	0.3	0.4
	11	23	5.4	3.0	2.1	1.0	0.6	0.7	0.2	0.1	0.1	0.1	0.2	0.3	0.2	0.5
swl = +0.7 ft																
NW	10.3	6.9	1.3	0.7	0.4	0.3	0.2	0.2	0.1	0.1	0.2	0.1	0.2	0.1	0.2	0.2
WNW	9.7	5.9	1.7	1.1	0.6	0.4	0.3	0.2	0.1	0.2	0.3	0.1	0.3	0.1	0.2	0.2
West	7.1	8.5	3.3	2.6	1.6	1.1	0.8	0.7	0.2	0.2	0.3	0.2	0.3	0.3	0.6	0.6
WSW	7.0	8.9	4.4	3.1	2.0	1.3	1.0	0.9	0.3	0.3	0.5	0.2	0.4	0.4	0.7	0.7
SW	6.8	8.2	4.2	2.9	1.8	1.2	0.9	0.8	0.3	0.2	0.4	0.1	0.4	0.4	0.4	0.6

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entrance and berthing area, respectively, for 7-sec, 8.9-ft test waves from the west-southwest. Typical wave patterns secured for Plan 3 are shown in Photos 37-51.

The general movement of tracer material and subsequent deposits obtained for Plan 3 are shown in Photos 52-66 for representative test waves from the five selected directions. For waves from the northwest and west-northwest, sediment tracer material north of the harbor moved southerly along the shoreline with some accumulating against the structure and some migrating seaward adjacent to the breakwater. Only 11-sec, 16-ft test waves from the west-northwest resulted in small amounts of sediment moving around the head of the north breakwater. Sediment tracer south of the harbor moved in a counterclockwise eddy. Some migrated northerly along the shoreline accumulating against the breakwater, and some deposited in the eddy south of the structure. For test waves from the west, tracer material north of the harbor moved shoreward and split with some moving southerly and some moving northerly. Sediment on the north shoreline generally moved northerly for test waves from the west-southwest and southwest. Sediment tracer material south of the harbor migrated to the north for test waves from the west, west-southwest, and southwest. Some sediment accumulated against the south breakwater and some deposited seaward south of the structure. Small amounts of sediment tracer migrated around the head of the south breakwater for 9-sec, 19-ft test waves from the west-southwest and southwest.

Discussion of test results

Wave heights obtained in the harbor with no structure installed (Plan 1) indicated that the 1.5-ft wave height criterion in the berthing area would be exceeded by test waves from each direction. Maximum wave heights in the berthing area ranged from 2.7 to 4.0 ft depending on wave direction. Maximum wave heights (4.0 ft) were obtained for test waves from the northwest which, based on hindcast data (Table 1), is the predominant wave direction at Barking Sands.

Sediment tracer tests conducted with no structures installed (Plan 1) revealed that tracer material would deposit in the entrance channel for test waves from each direction. Sediment north of the harbor moved southerly into the entrance channel for waves from the northwest and west-northwest, and sediment south of the harbor migrated northerly into the entrance channel for waves from the west, west-southwest, and southwest. Based on hindcast data (Table 1), waves from the northwest and west-northwest are significantly more dominant than the other directions. This indicates that if sediment material is moving in the area, net direction of movement would be from north to south. An assessment of littoral transport at the Pacific Missile Range Facility throughout the winter of 1985-1986 (Sea Engineering, Inc. 1986) indicated that significant sand transport rates fronting the study area are possible due to strong southward flowing long-shore currents in the surf zone and several possible sand sources. The lack of significant changes in the beach profiles monitored, however, indicated that no significant net transport occurred into or out of the measured area during the winter 1985-1986 time period.

Wave heights obtained in the harbor for waves from the predominant northwest direction for the offshore breakwater plan (Plan 2) revealed that the 1.5-ft wave height criterion in the berthing area would be exceeded for several test waves. In addition, sediment tracer tests indicated that tracer material would deposit in the entrance channel for test waves from the northwest.

Wave heights obtained in the harbor with the dual shore-connected breakwater installed (Plan 3) indicated that the wave height criterion would be exceeded by only 0.1 ft at one gage location (gage 9) for two wave conditions (9-sec, 16-ft waves from the west-southwest and 11-sec, 13-ft waves from the west). Considering wave protection afforded the berthing area versus implied construction costs, it appeared not to be economically feasible to modify the breakwater plan in order to reduce the wave height by 0.1 ft at the one gage location.

Sediment tracer tests conducted for the dual shore-connected breakwater plan (Plan 3) revealed, in general, that tracer material would accumulate against the breakwaters or deposit in eddies north and south of the structures. Sediment migrated around the heads of the jetties for 16-ft waves from the west-northwest and 19-ft waves from the west-southwest and southwest. This sediment bypassed the harbor entrance for the southwest waves and only slight deposits resulted at the heads of the structures for waves from the west-northwest and west-southwest. Considering the frequency of occurrence of these large wave conditions, it appears there will be no appreciable shoaling of the harbor entrance for initial conditions. Sediment movement patterns around the breakwater heads and into the entrance channel could change if sediments build up on the sea sides of the breakwaters. The breakwaters may prevent natural bypassing along the shoreline for normal wave conditions, however. If this problem is encountered after breakwater construction, artificial sand bypassing methodologies may be considered to mitigate downcoast erosion.

5 Conclusions

Based on the results of the coastal hydraulic model investigation reported herein, it is concluded that:

a. For the harbor basin and entrance channel with no structures installed (Plan 1), wave heights in the berthing area will exceed the established 1.5-ft criterion for test waves from all five test directions.

b. For the harbor basin and entrance channel with no structures installed (Plan 1), sediment will migrate into the entrance channel for test waves from all five directions.

c. For the offshore breakwater plan (Plan 2), wave heights in the berthing area will exceed the established criterion for test waves from the predominant northwest direction.

d. For the offshore breakwater plan (Plan 2), sediment tracer north of the harbor will migrate southerly into the entrance channel for test waves from the predominant northwest direction.

e. For the dual shore-connected breakwater plan (Plan 3), wave heights will exceed the criterion in the berthing area by only 0.1 ft at one location.

f. For the dual shore-connected breakwater plan (Plan 3), no appreciable shoaling of the harbor entrance will occur.

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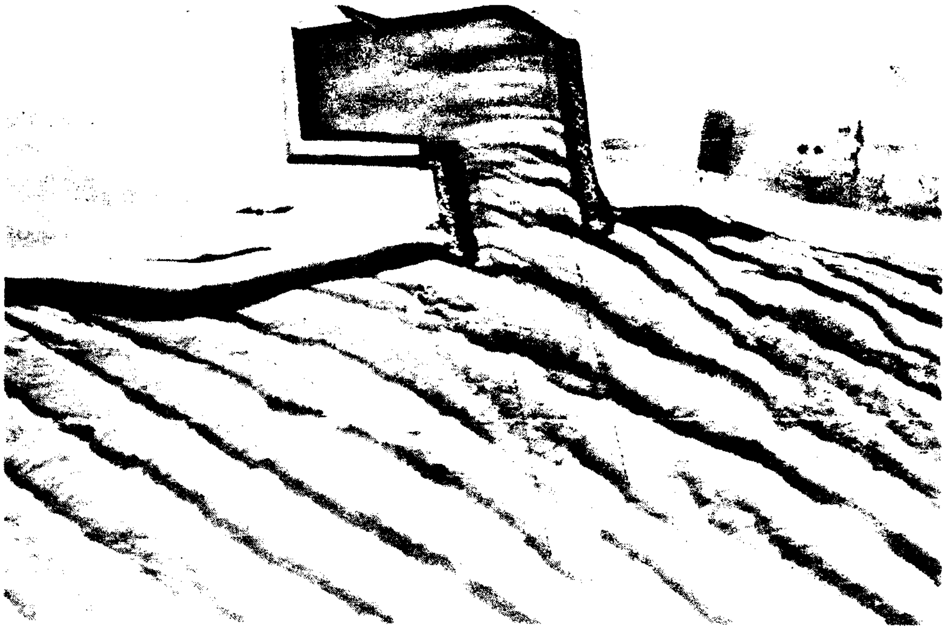


Photo 1. Typical wave patterns for Plan 1; 7-sec, 10-ft waves from the northwest; swl = +4.4 ft

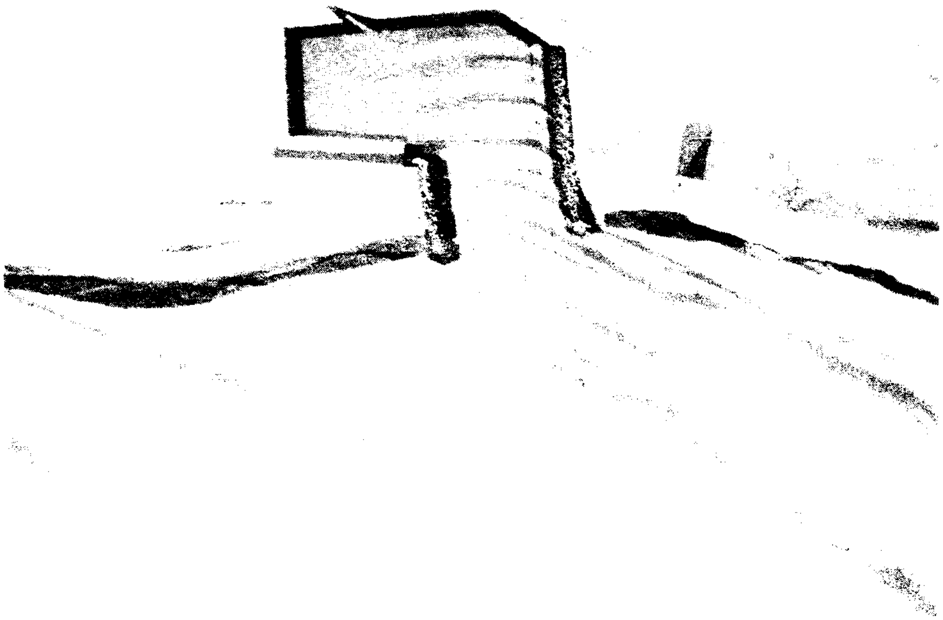


Photo 2. Typical wave patterns for Plan 1; 13-sec, 16-ft waves from the northwest; swl = +4.4 ft

Photo 3. Typical wave patterns for Plan 1; 10.3-sec, 6.9-ft waves from the northwest; swl = +0.7 ft

Photo 4. Typical wave patterns for Plan 1; 7-sec, 10-ft waves from the west-northwest; swl = +4.4 ft

Photo 5. Typical wave patterns for Plan 1; 11-sec. 16-ft waves from the west-northwest; swl = +4.4 ft

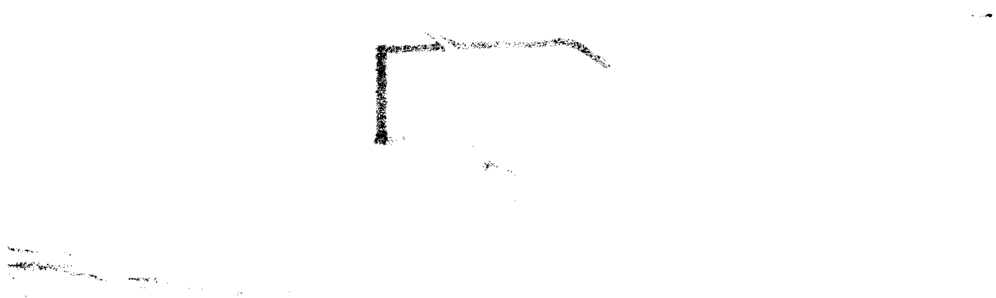


Photo 6. Typical wave patterns for Plan 1; 9.7-sec, 5.9-ft waves from the west-northwest; swl = +0.7 ft

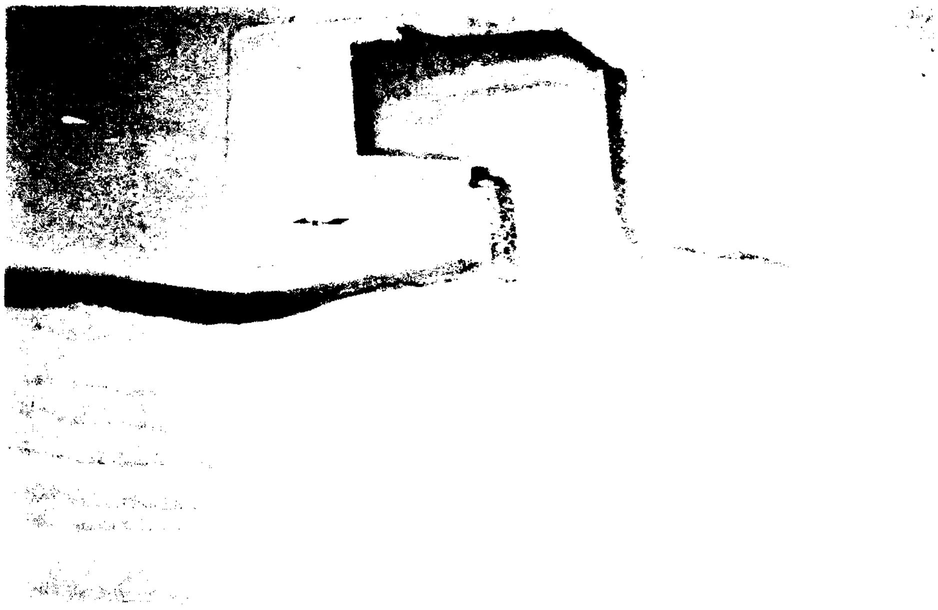


Photo 7. Typical wave patterns for Plan 1; 7-sec, 10-ft waves from the west; swl = +4.4 ft

Photo 8. Typical wave patterns for Plan 1; 9-sec, 16-ft waves from the west; swl = +4.4 ft

Photo 9. Typical wave patterns for Plan 1; 7.1-sec, 8.5-ft waves from the west; swl = +0.7 ft

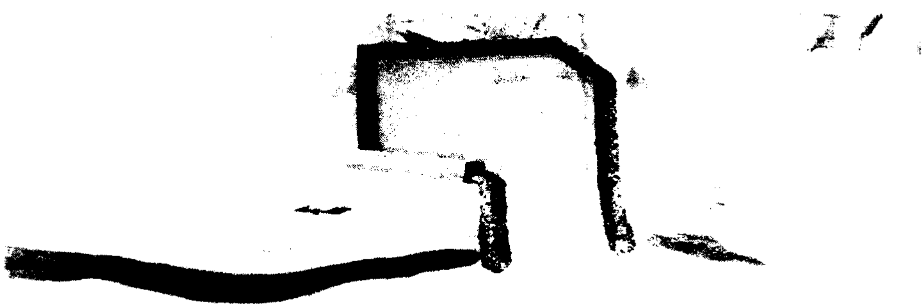


Photo 10. Typical wave patterns for Plan 1; 7-sec, 10-ft waves from the west-southwest; swl = +4.[illegible] ft

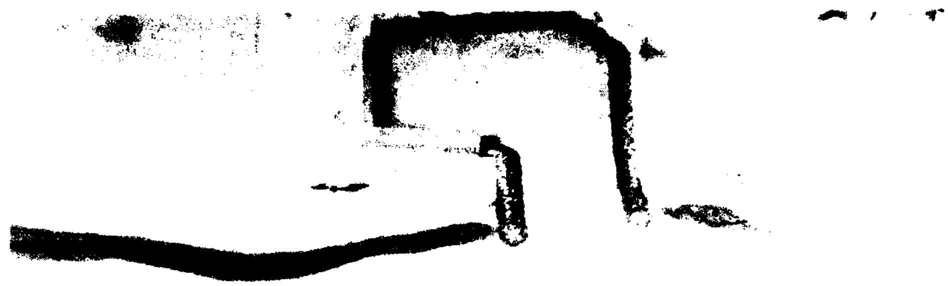


Photo 11. Typical wave patterns for Plan 1; 9-sec, 19-ft waves from the west-southwest; swl = +4.4 ft

Photo 12. Typical wave patterns for Plan 1; 7-sec, 8.9-ft waves from the west-southwest; swl = +0.7 ft

Photo 13. Typical wave patterns for Plan 1; 7-sec, 10-ft waves from the southwest; swl = +4.4 ft

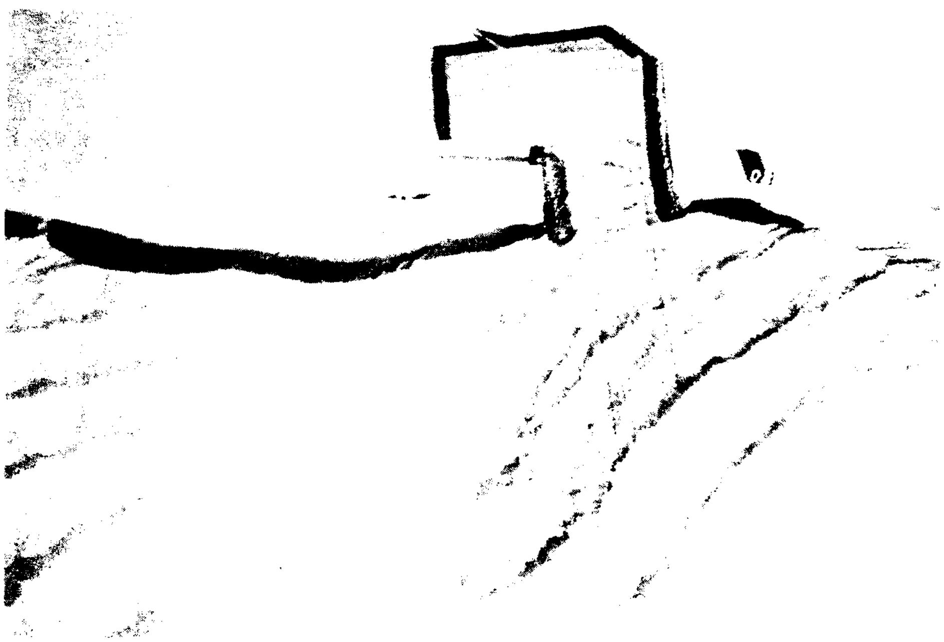


Photo 14. Typical wave patterns for Plan 1; 9-sec, 19-ft waves from the southwest; swl = +4.4 ft

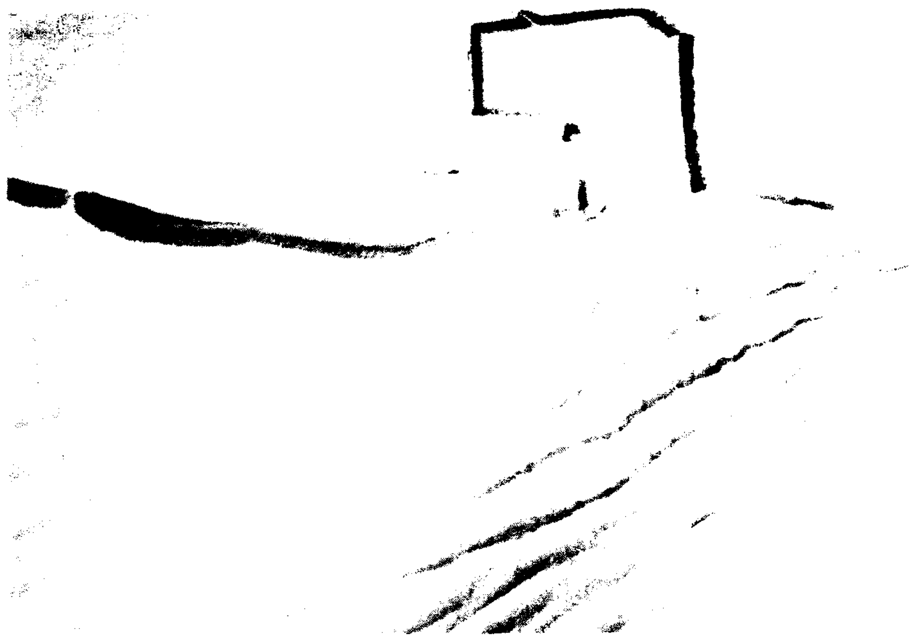


Photo 15. Typical wave patterns for Plan 1; 6.8-sec, 8.2-ft waves from the southwest; swl = +0.7 ft

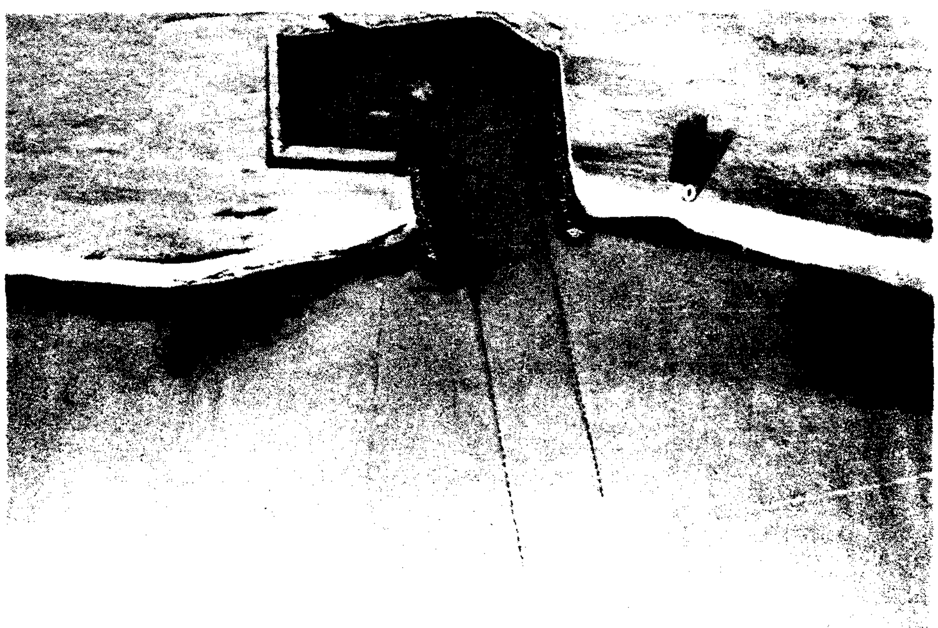


Photo 16. General movement of tracer material and subsequent deposits for Plan 1; 7-sec, 10-ft waves from the northwest; swl = +4.4 ft

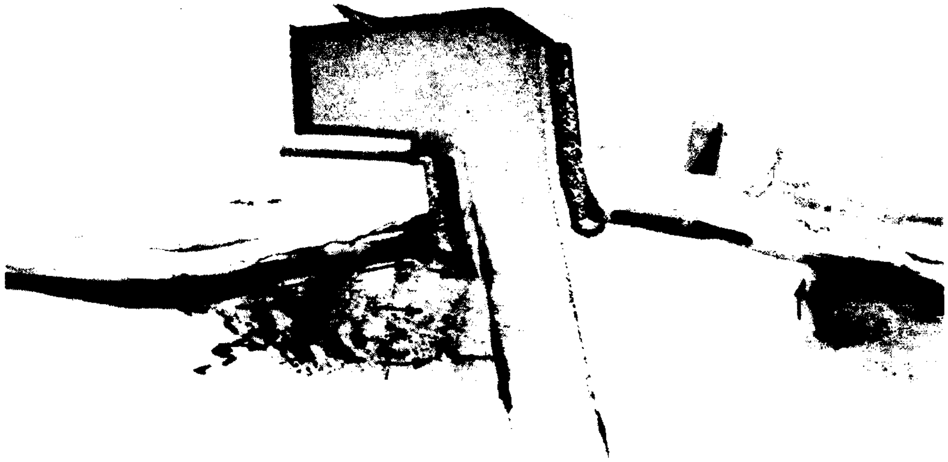


Photo 17. General movement of tracer material and subsequent deposits for Plan 1; 13-sec, 16-ft waves from the northwest; swl = +4.4 ft

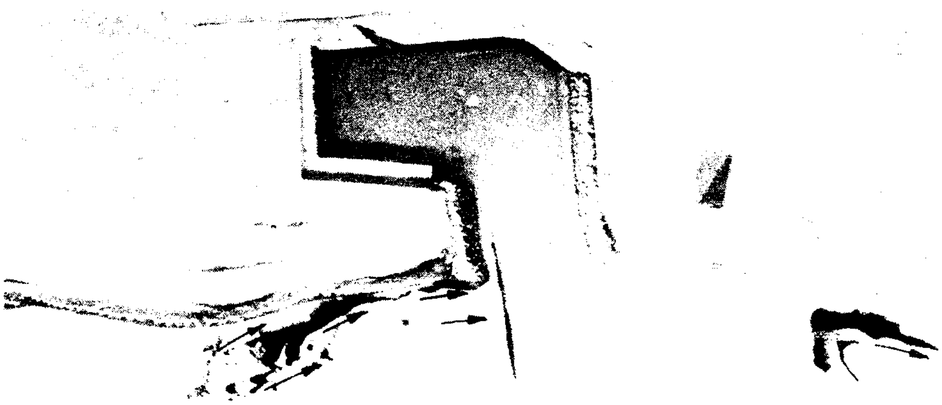


Photo 18. General movement of tracer material and subsequent deposits for Plan 1: 10.3-sec, 6.9-ft waves from the northwest; swl = +0.7 ft

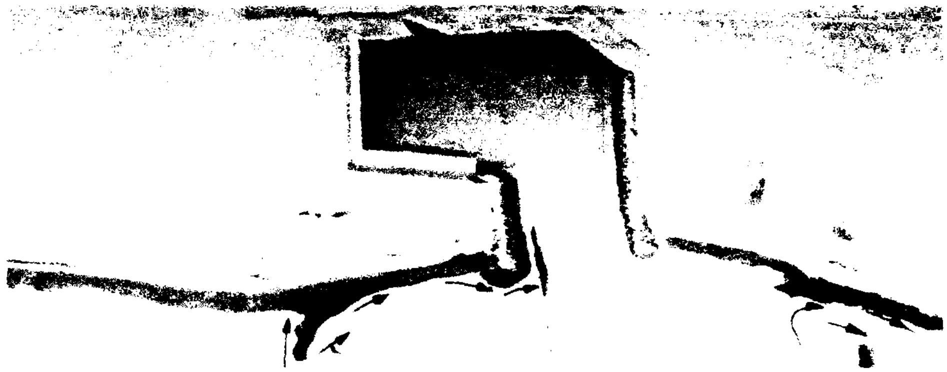


Photo 19. General movement of tracer material and subsequent deposits for Plan 1: 7-sec, 10-ft waves from the west-northwest; swl = +4.4 ft

Photo 20. General movement of tracer material and subsequent deposits for Plan 1; 11-sec, 16-ft waves from the west-northwest; swl = +4.4 ft

Photo 21. General movement of tracer material and subsequent deposits for Plan 1; 9.7-sec, 5.9-ft waves from the west-northwest; swl = +0.7 ft

F' oto 22. General movement of tracer material and subsequent deposits for Plan 1; 7-sec, 10-ft waves from the west; swl = +4.4 ft

Photo 23. General movement of tracer material and subsequent deposits for Plan 1; 9-sec, 16-ft waves from the west; swl = +4.4 ft

Photo 24. General movement of tracer material and subsequent deposits for Plan 1; 7.1-sec, 8.5-ft waves from the west; swl = +0.7 ft

Photo 25. General movement of tracer material and subsequent deposits for Plan 1; 7-sec, 10-ft waves from the west-southwest; swl = +4.4 ft

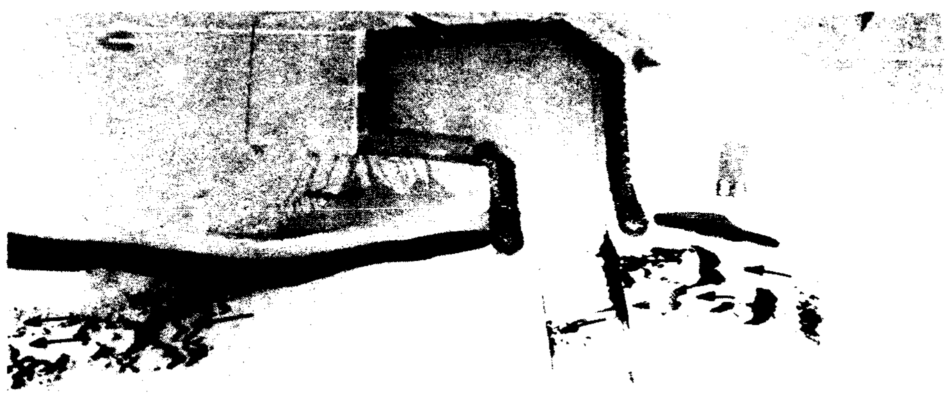


Photo 26. General movement of tracer material and subsequent deposits for Plan 1; 9-sec, 19-ft waves from the west-southwest; swl = +4.4 ft

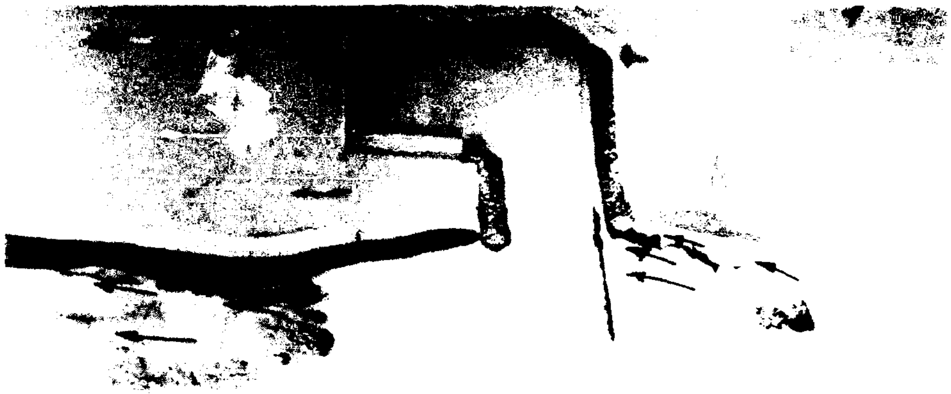


Photo 27. General movement of tracer material and subsequent deposits for Plan 1; 7-sec, 8.9-ft waves from the west-southwest; swl = +0.7 ft

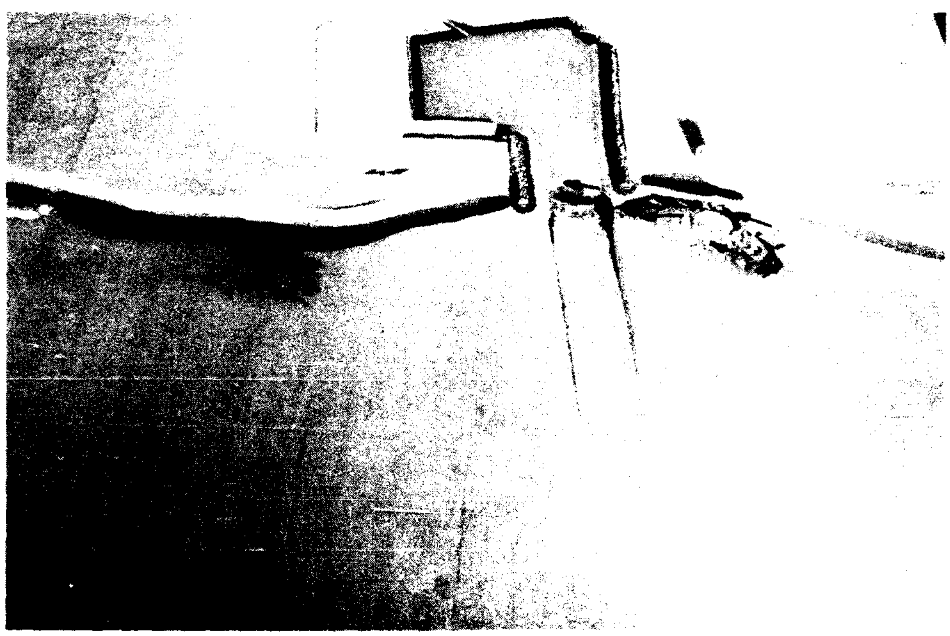


Photo 28. General movement of tracer material and subsequent deposits for Plan 1; 7-sec, 10-ft waves from the southwest; swl = +4.4 ft

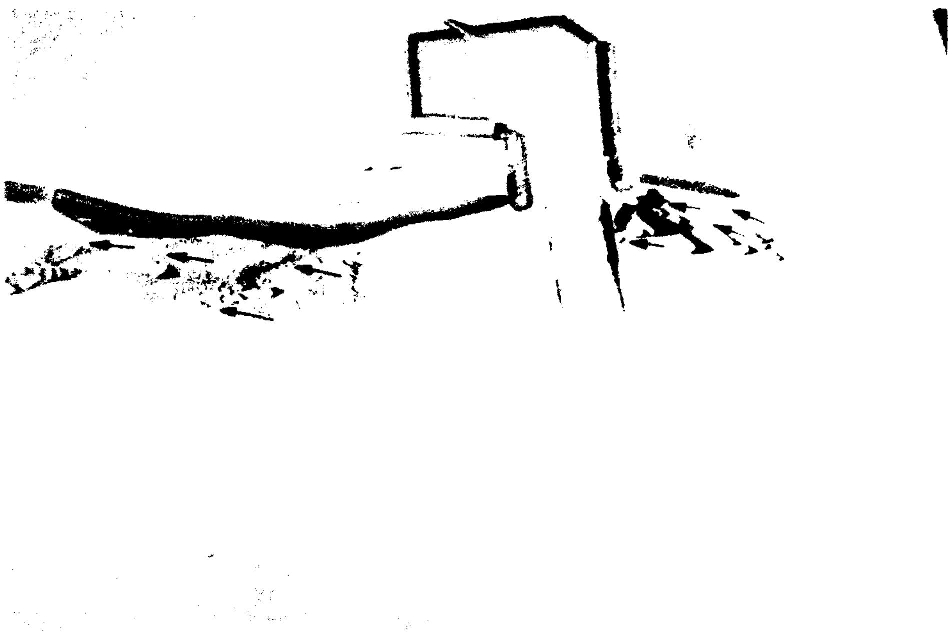


Photo 29. General movement of tracer material and subsequent deposits for Plan 1, 9-sec, 19-ft waves from the southwest; swl = +4.4 ft

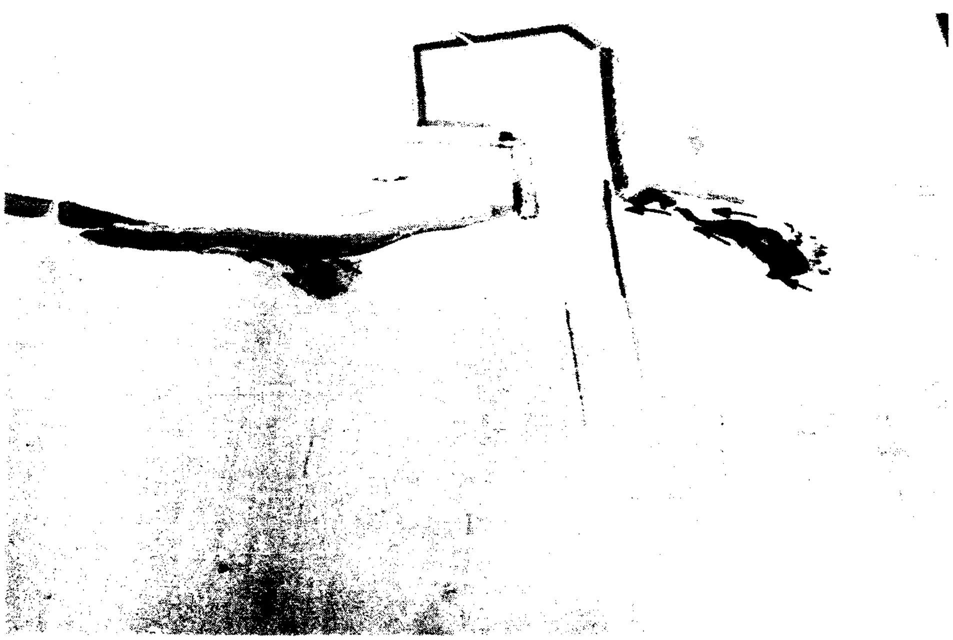


Photo 30. General movement of tracer material and subsequent deposits for Plan 1; 6.8-sec, 8.2-ft waves from the southwest; swl = +0.7 ft

Photo 31. Typical wave patterns for Plan 2; 7-sec, 10-ft waves from the northwest; swl = +4.4 ft

Photo 32. Typical wave patterns for Plan 2; 13-sec, 16-ft waves from the northwest; swl = +4.4 ft

Photo 33. Typical wave patterns for Plan 2; 10.3-sec, 6.9-ft waves from the northwest; swl = +0.7 ft

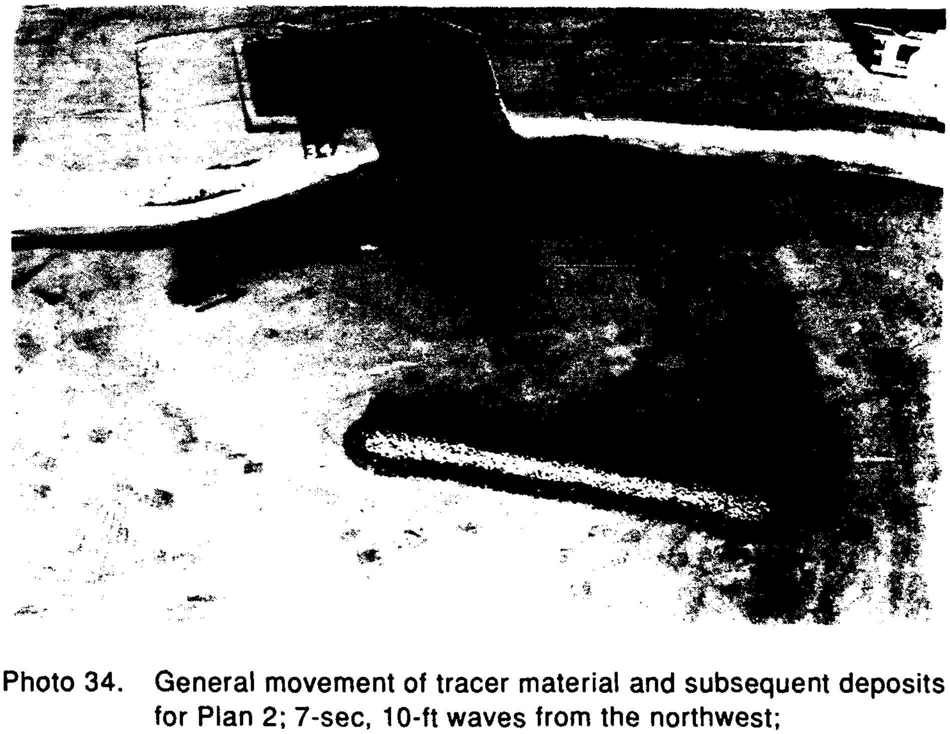


Photo 34. General movement of tracer material and subsequent deposits for Plan 2; 7-sec, 10-ft waves from the northwest; swl = +4.4 ft

Photo 35. General movement of tracer material and subsequent deposits for Plan 2; 13-sec, 16-ft waves from the northwest; swl = +4.4 ft

Photo 36. General movement of tracer material and subsequent deposits for Plan 2; 10.3-sec, 6.9-ft waves from the northwest; swl = +0.7 ft

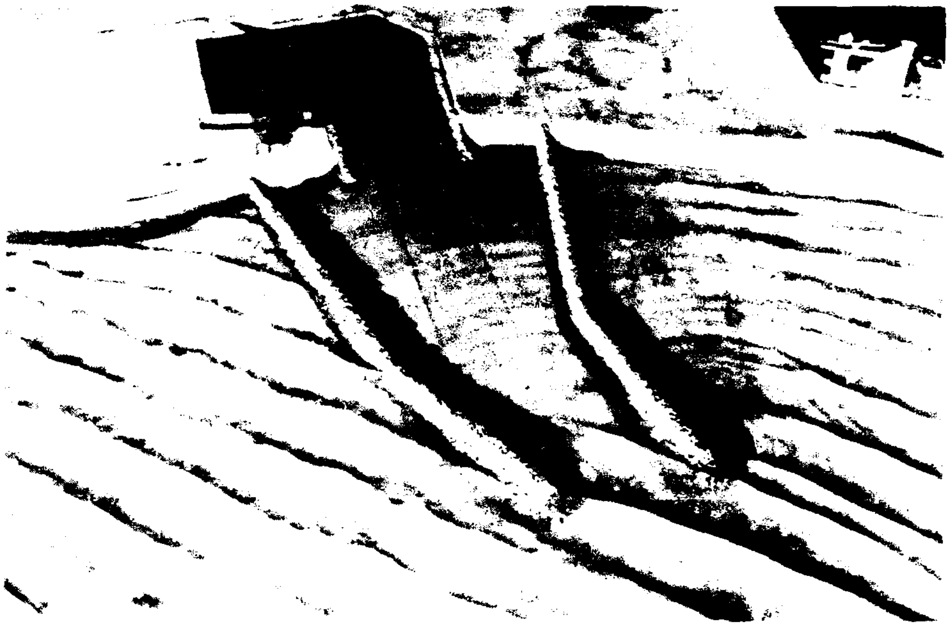


Photo 37. Typical wave patterns for Plan 3; 7-sec, 10-ft waves from the northwest; swl = +4.4 ft

Photo 38. Typical wave patterns for Plan 3; 13-sec, 16-ft waves from the northwest; swl = +4.4 ft

Photo 39. Typical wave patterns for Plan 3; 10.3-sec, 6.9-ft waves from the northwest; swl = +0.7 ft

Photo 40. Typical wave patterns for Plan 3; 7-sec, 10-ft waves from the west-northwest; swl = +4.4 ft

Photo 41. Typical wave patterns for Plan 3; 11-sec, 16-ft waves from the west-northwest; swl = +4.4 ft

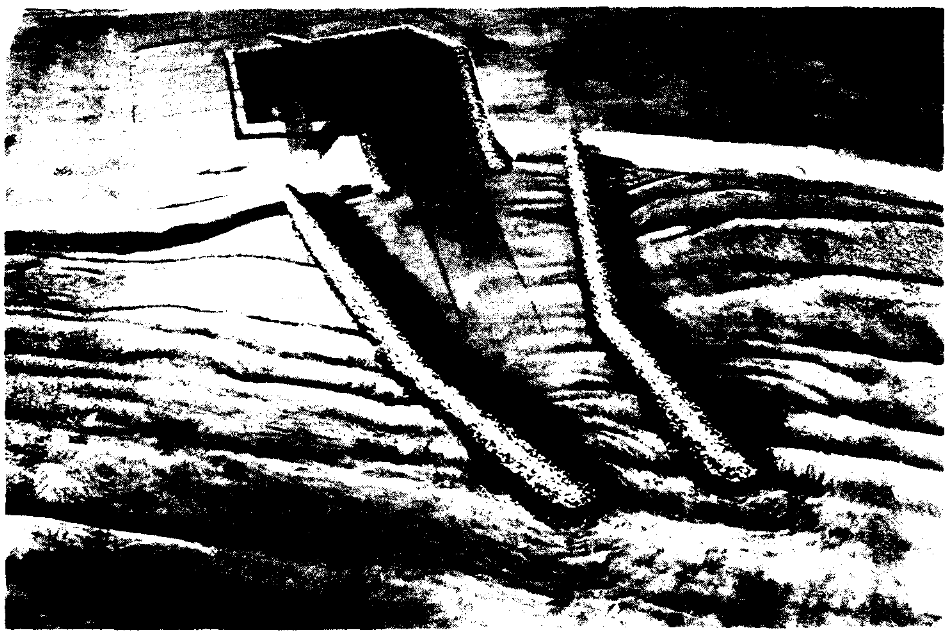


Photo 42. Typical wave patterns for Plan 3; 9.7-sec, 5.9-ft waves from the west-northwest; swl = +0.7 ft

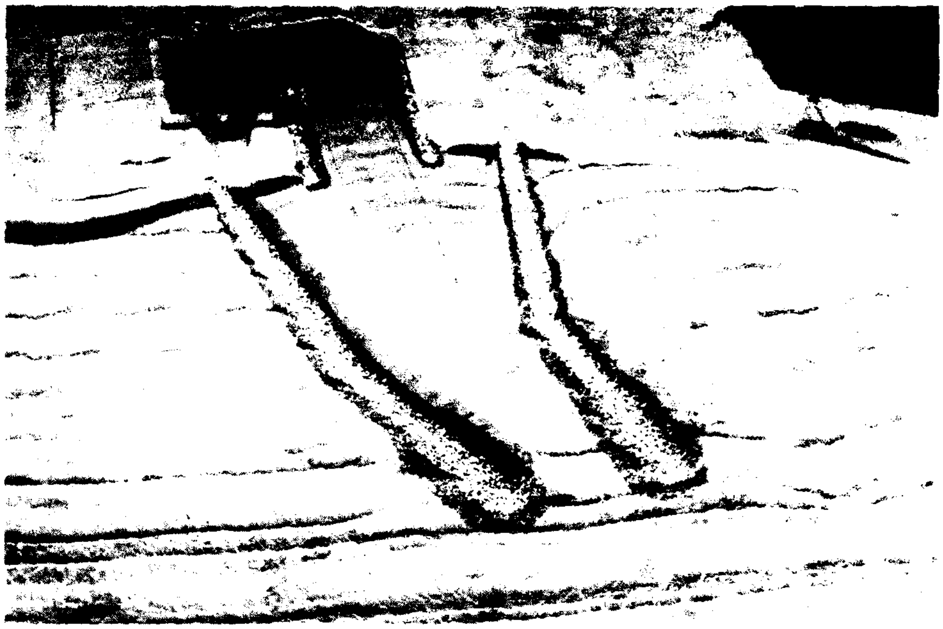


Photo 43. Typical wave patterns for Plan 3; 7-sec, 10-ft waves from the west; swl = +4.4 ft

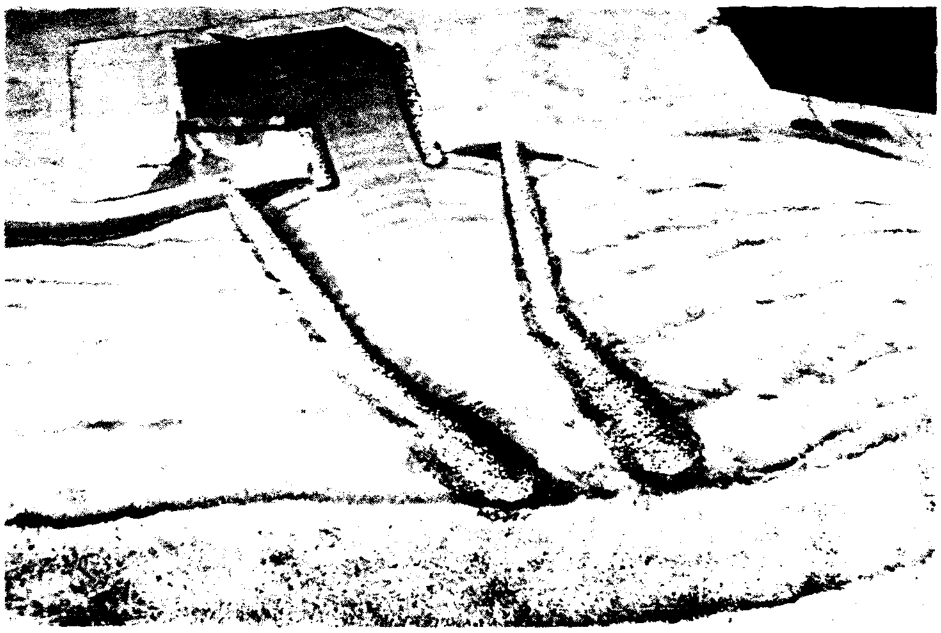


Photo 44. Typical wave patterns for Plan 3; 9-sec, 16-ft waves from the west; swl = +4.4 ft

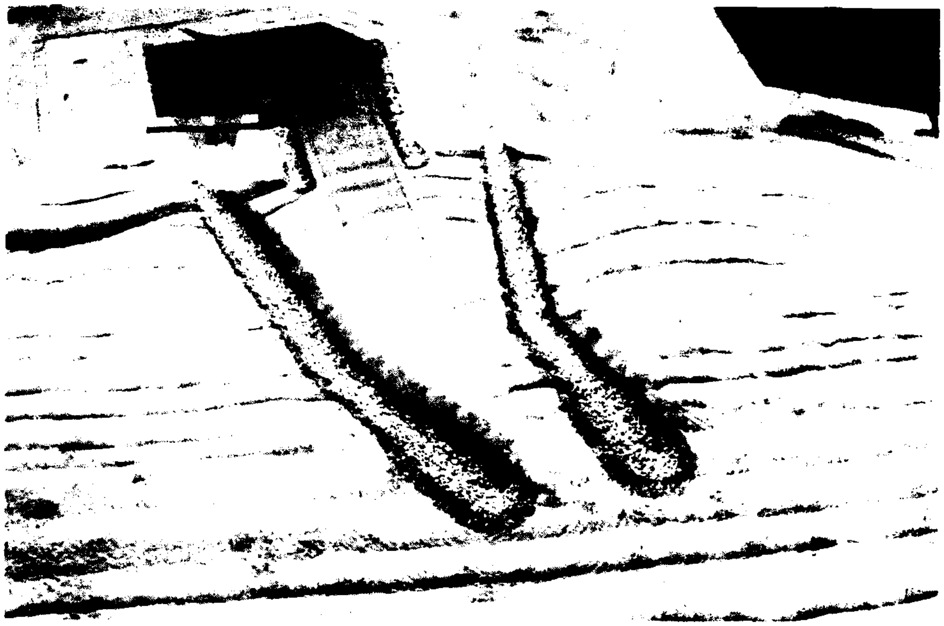


Photo 45. Typical wave patterns for Plan 3; 7.1-sec, 8.5-ft waves from the west; swl = +0.7 ft

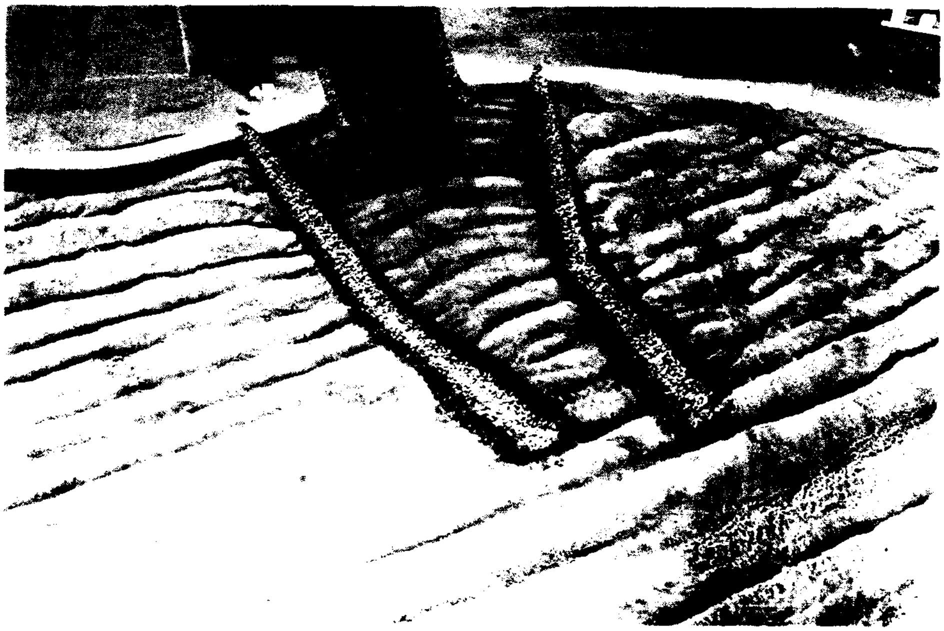


Photo 46. Typical wave patterns for Plan 3; 7-sec, 10-ft waves from the west-southwest; swl = +4.4 ft

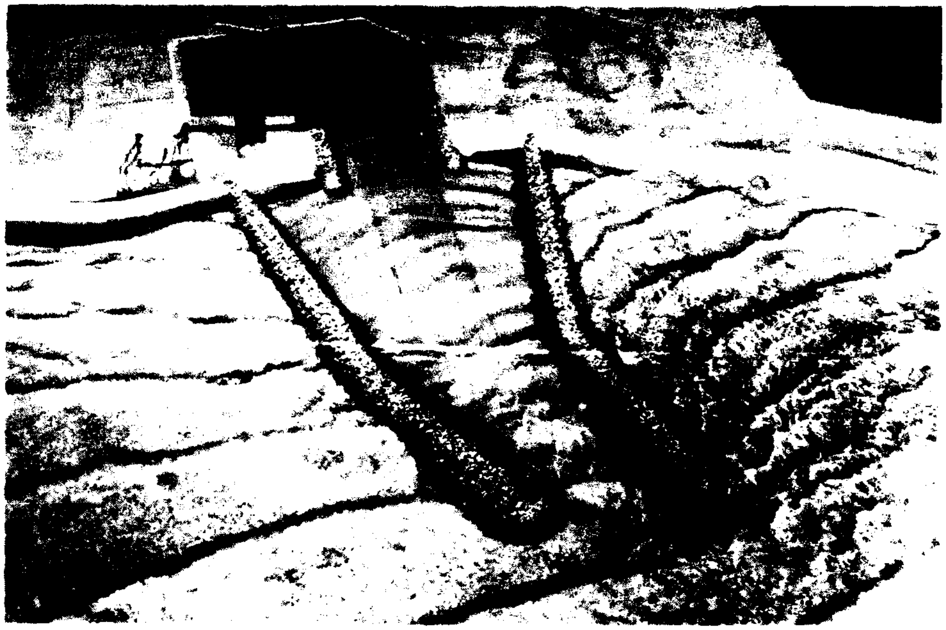


Photo 47. Typical wave patterns for Plan 3; 9-sec, 19-ft waves from the west-southwest; swl = +4.4 ft

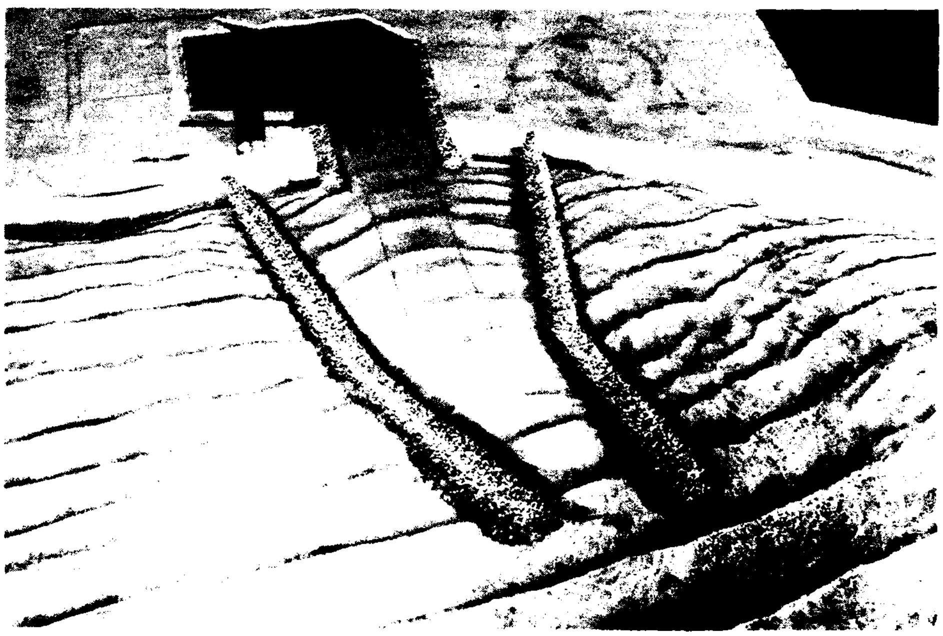


Photo 48. Typical wave patterns for Plan 3; 7-sec, 8.9-ft waves from the west-southwest; swl = +0.7 ft

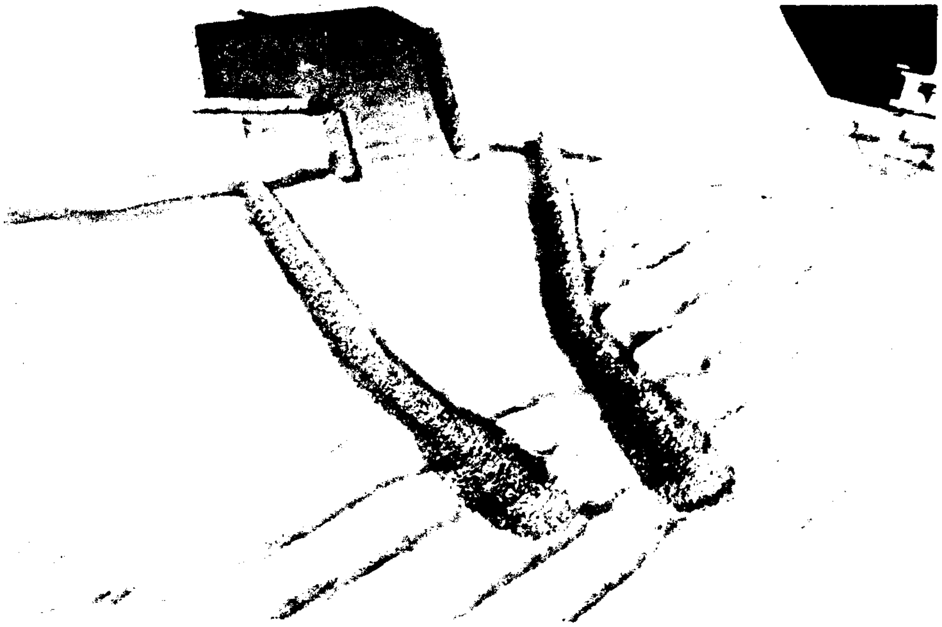


Photo 49. Typical wave patterns for Plan 3; 7-sec, 10-ft waves from the southwest; swl = +4.4 ft

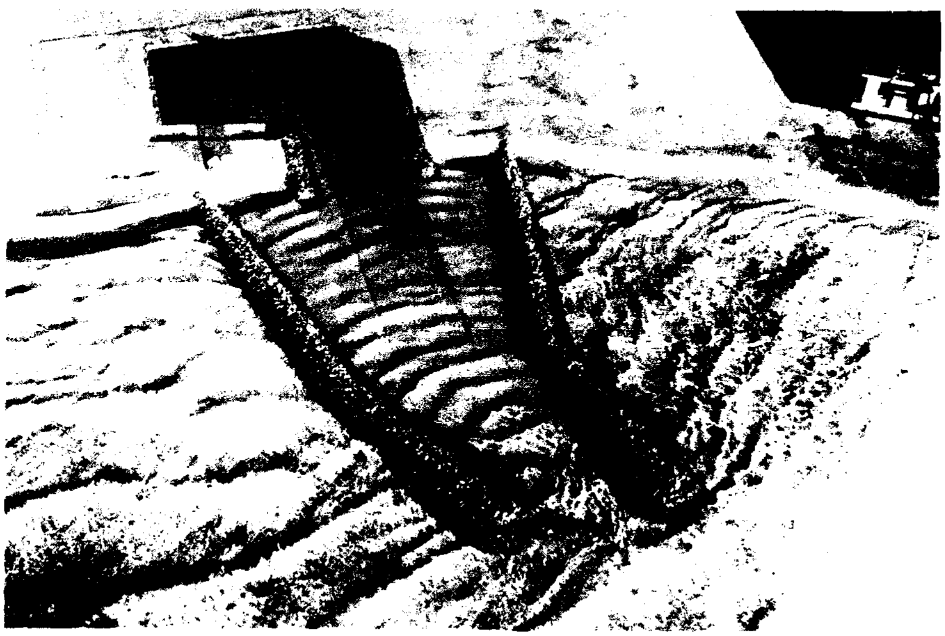


Photo 50. Typical wave patterns for Plan 3; 9-sec, 19-ft waves from the southwest; swl = +4.4 ft

Photo 51. Typical wave patterns for Plan 3; 6.8-sec, 8.2-ft waves from the southwest; swl = +0.7 ft

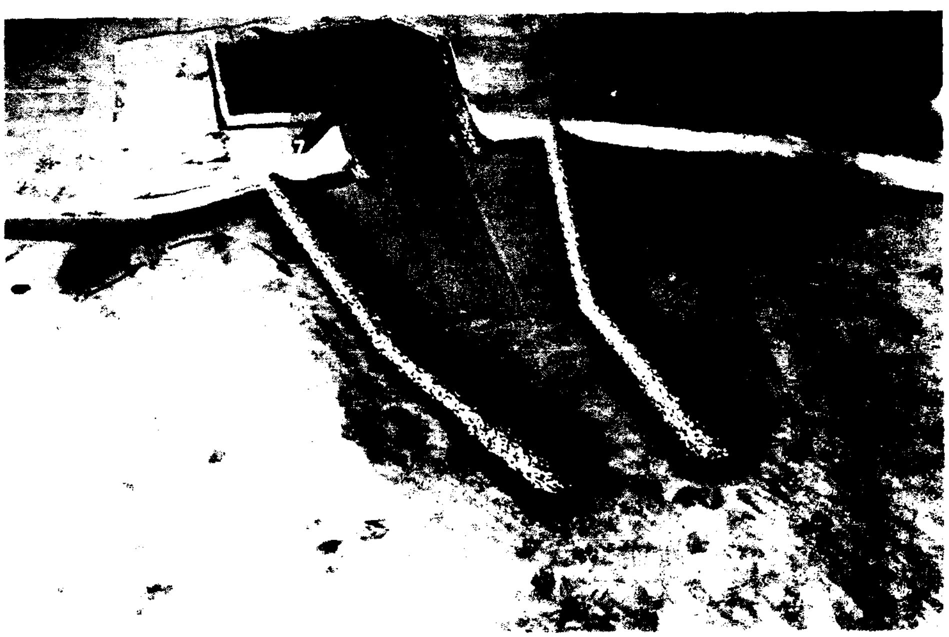


Photo 52. General movement of tracer material and subsequent deposits for Plan 3; 7-sec, 10-ft waves from the northwest; swl = +4.4 ft

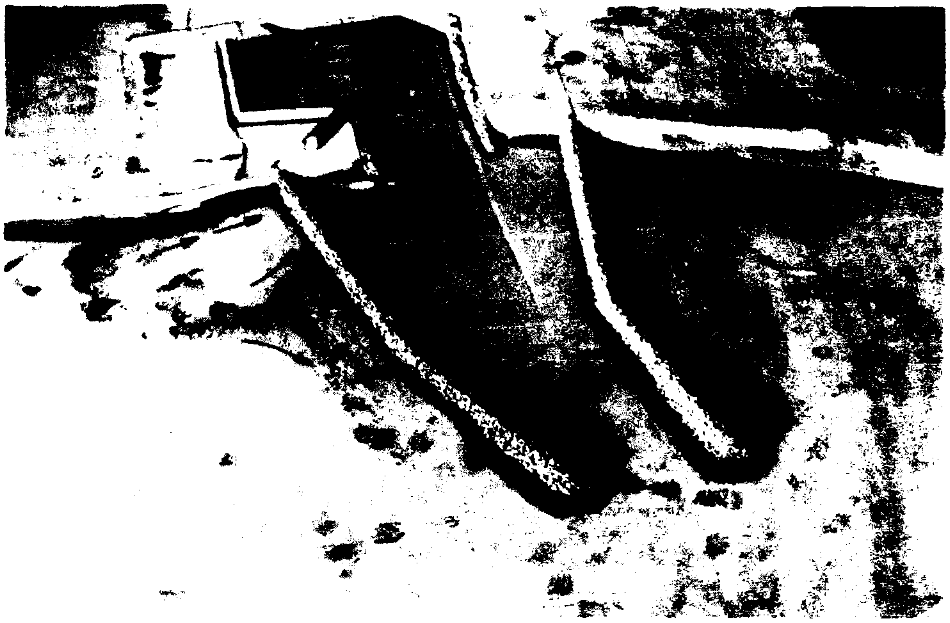


Photo 53. General movement of tracer material and subsequent deposits for Plan 3; 13-sec, 16-ft waves from the northwest; swl = +4.4 ft

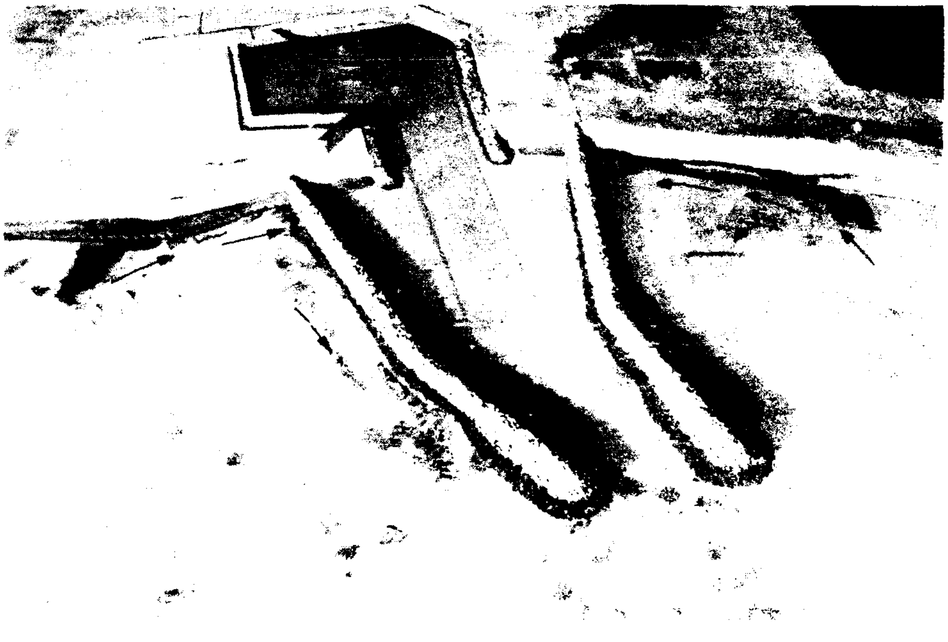


Photo 54. General movement of tracer material and subsequent deposits for Plan 3; 10.3-sec, 6.9-ft waves from the northwest; swl = +0.7 ft

Photo 55. General movement of tracer material and subsequent deposits for Plan 3; 7-sec, 10-ft waves from the west-northwest; swl = +4.4 ft

Photo 56. General movement of tracer material and subsequent deposits for Plan 3; 11-sec, 16-ft waves from the west-northwest; swl = +4.4 ft

Photo 57. General movement of tracer material and subsequent deposits for Plan 3; 9.7-sec, 5.9-ft waves from the west-northwest; swl = +0.7 ft

Photo 58. General movement of tracer matrial and subsequent deposits for Plan 3; 7-sec, 10-ft waves from the west; swl = +4.4 ft

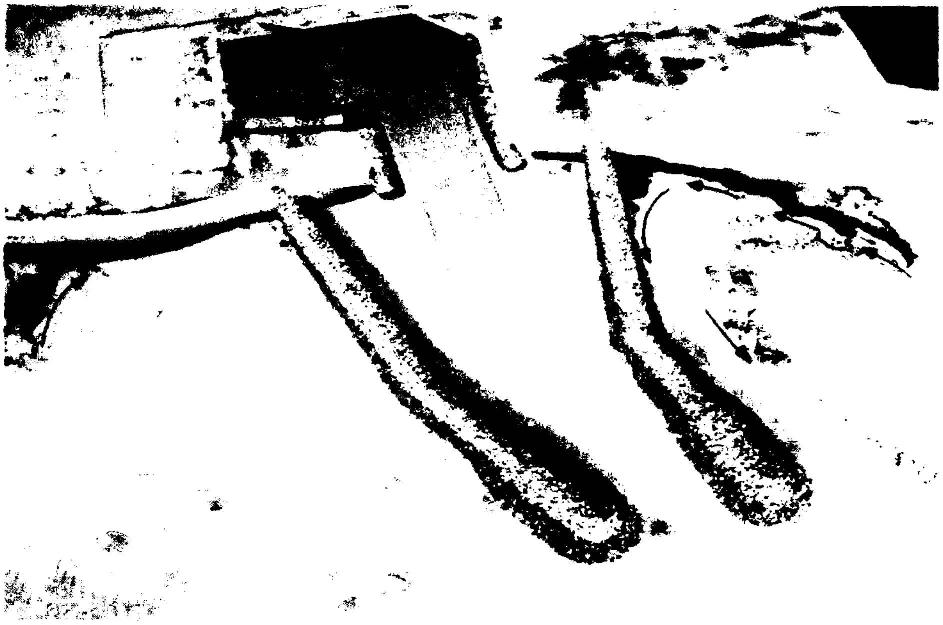


Photo 59. General movement of tracer material and subsequent deposits for Plan 3; 9-sec, 16-ft waves from the west; swl = +4.4 ft

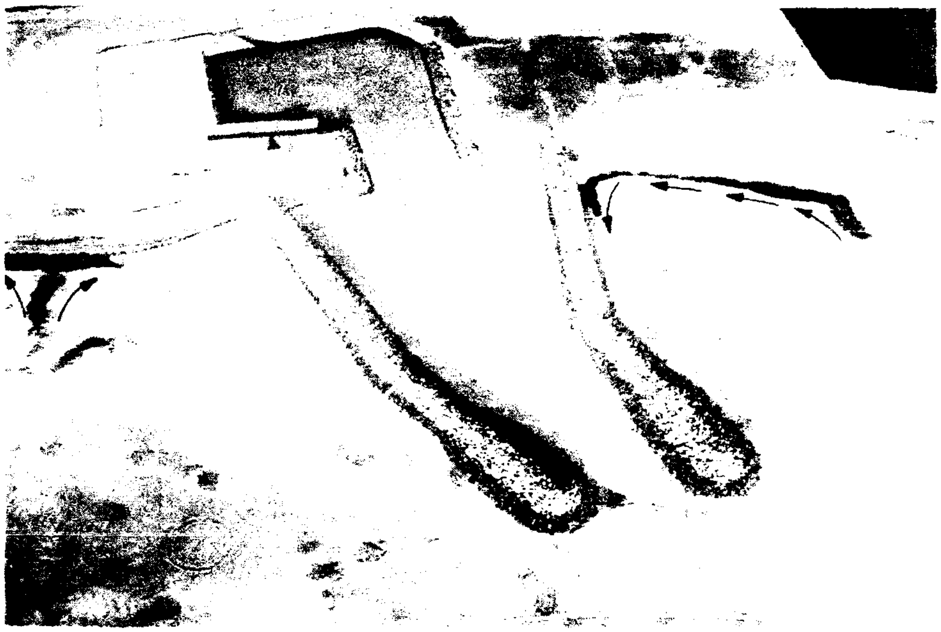


Photo 60. General movement of tracer material and subsequent deposits for Plan 3; 7.1-sec, 8.5-ft waves from the west; swl = +0.7 ft

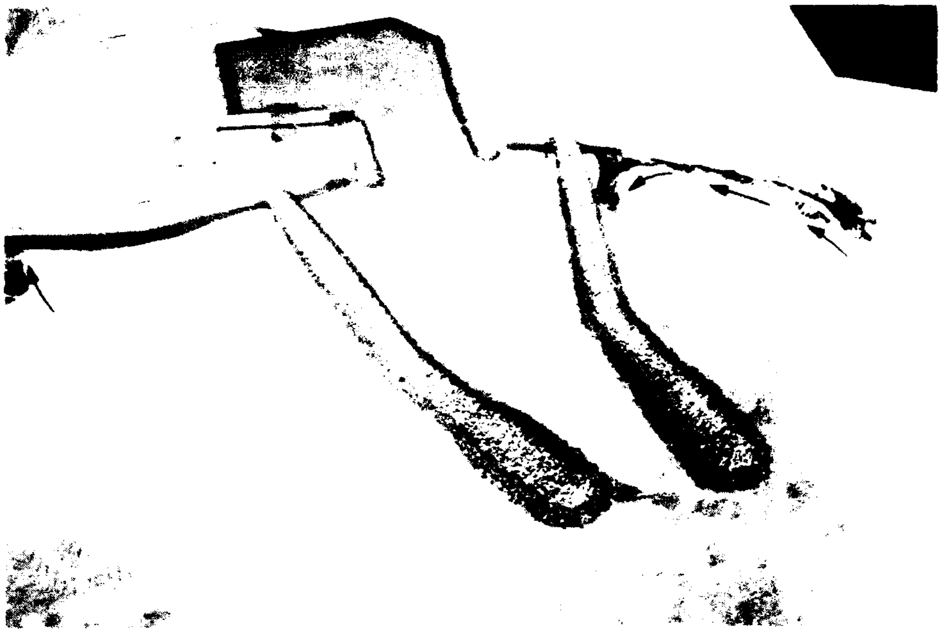


Photo 61. General movement of tracer material and subsequent deposits for Plan 3; 7-sec, 10-ft waves from the west-southwest; swl = +4.4 ft

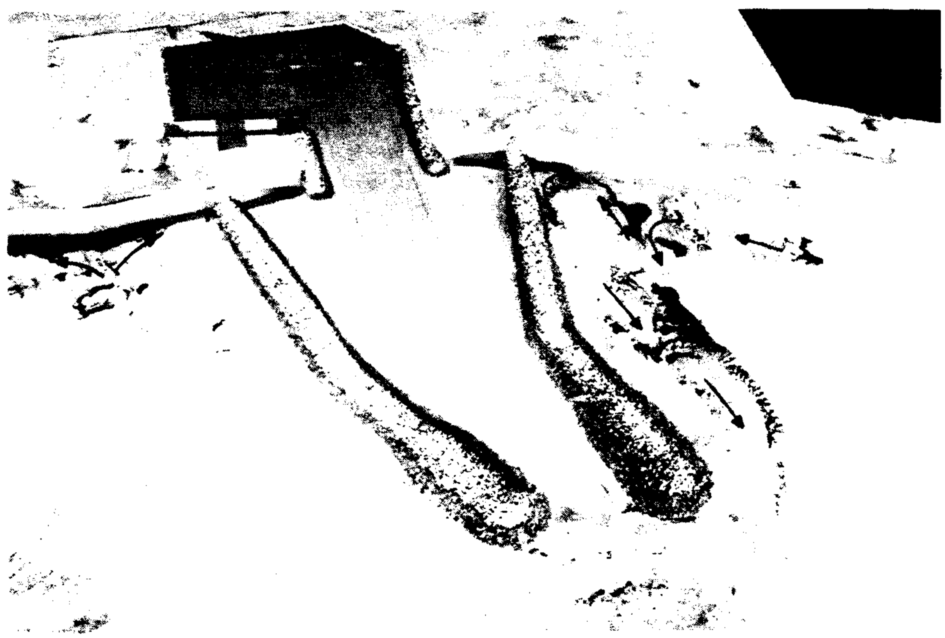


Photo 62. General movement of tracer material and subsequent deposits for Plan 3; 9-sec, 19-ft waves from the west-southwest; swl = +4.4 ft

Photo 63. General movement of tracer material and subsequent deposits for Plan 3; 7-sec, 8.9-ft waves from the west-southwest; swl = +0.7 ft

Photo 64. General movement of tracer material and subsequent deposits for Plan 3; 7-sec, 10-ft waves from the southwest; swl = +4.4 ft

Photo 65. General movement of tracer material and subsequent deposits for Plan 3; 9-sec, 19-ft waves from the southwest; swl = +4.4 ft

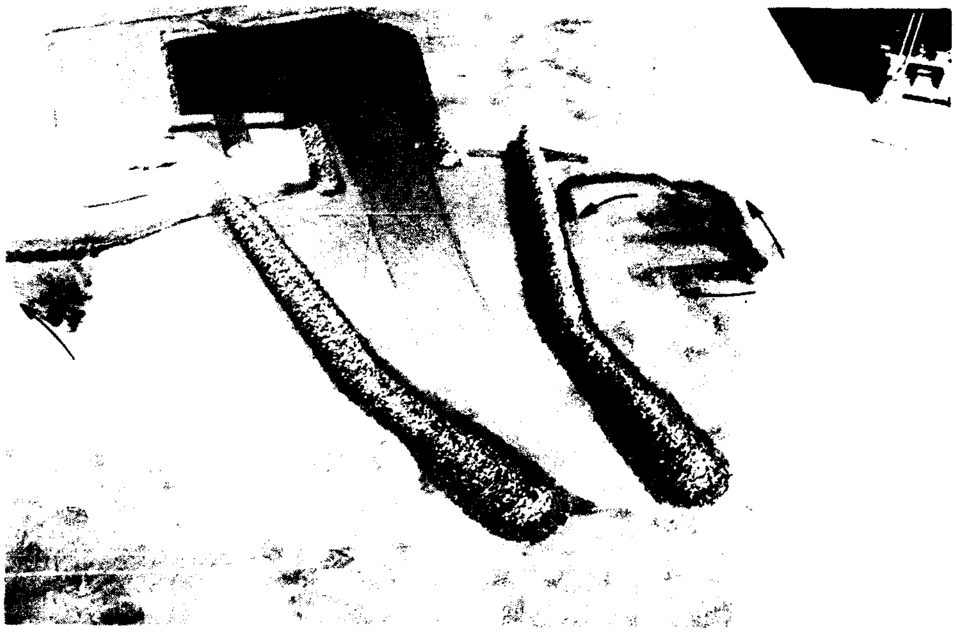
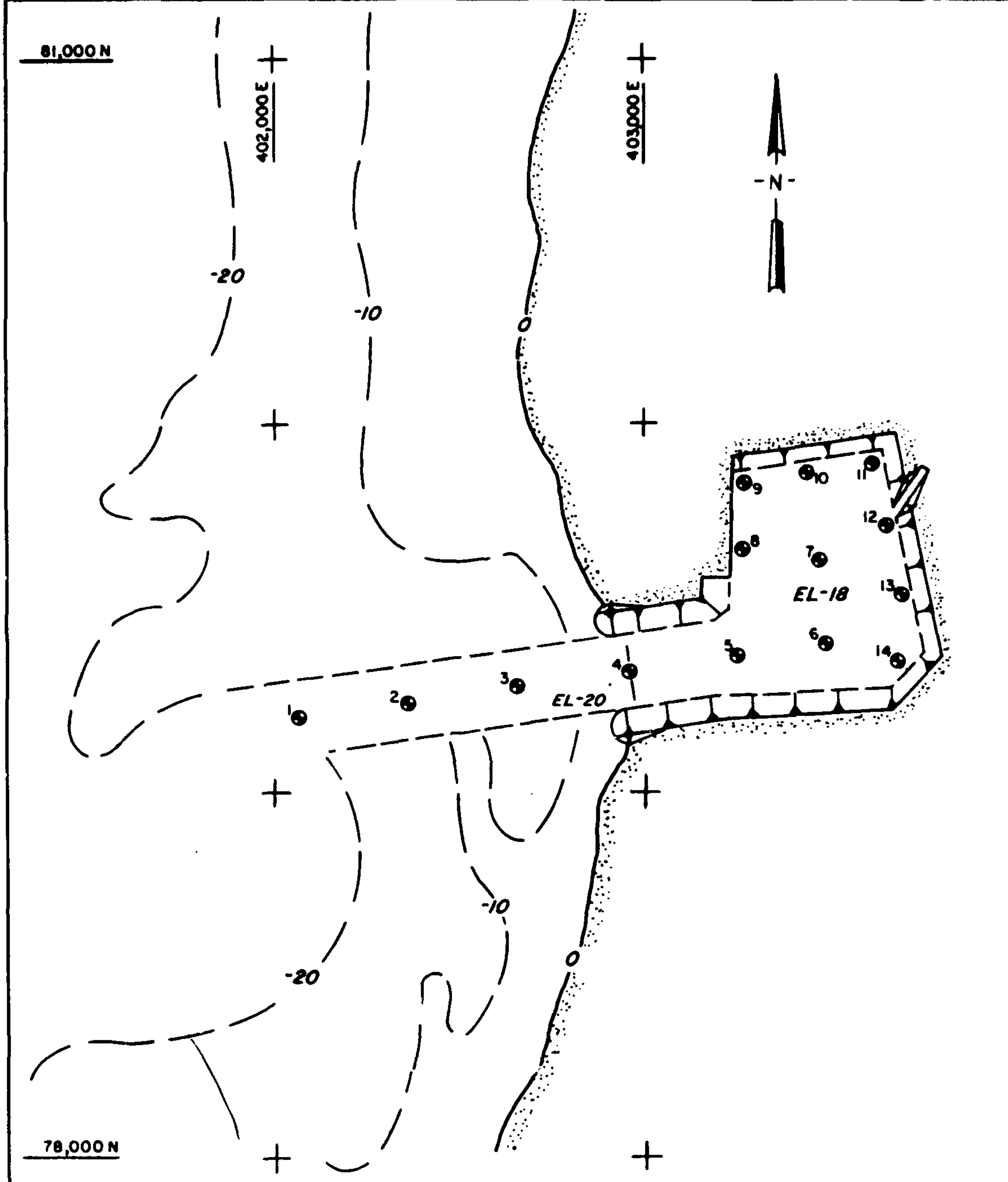


Photo 66. General movement of tracer material and subsequent deposits for Plan 3; 6.8-sec, 8.2-ft waves from the southwest; swl = +0.7 ft



LEGEND

1⊛ GAGE NUMBER AND LOCATION

NOTE: CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOWER LOW WATER (MLLW)

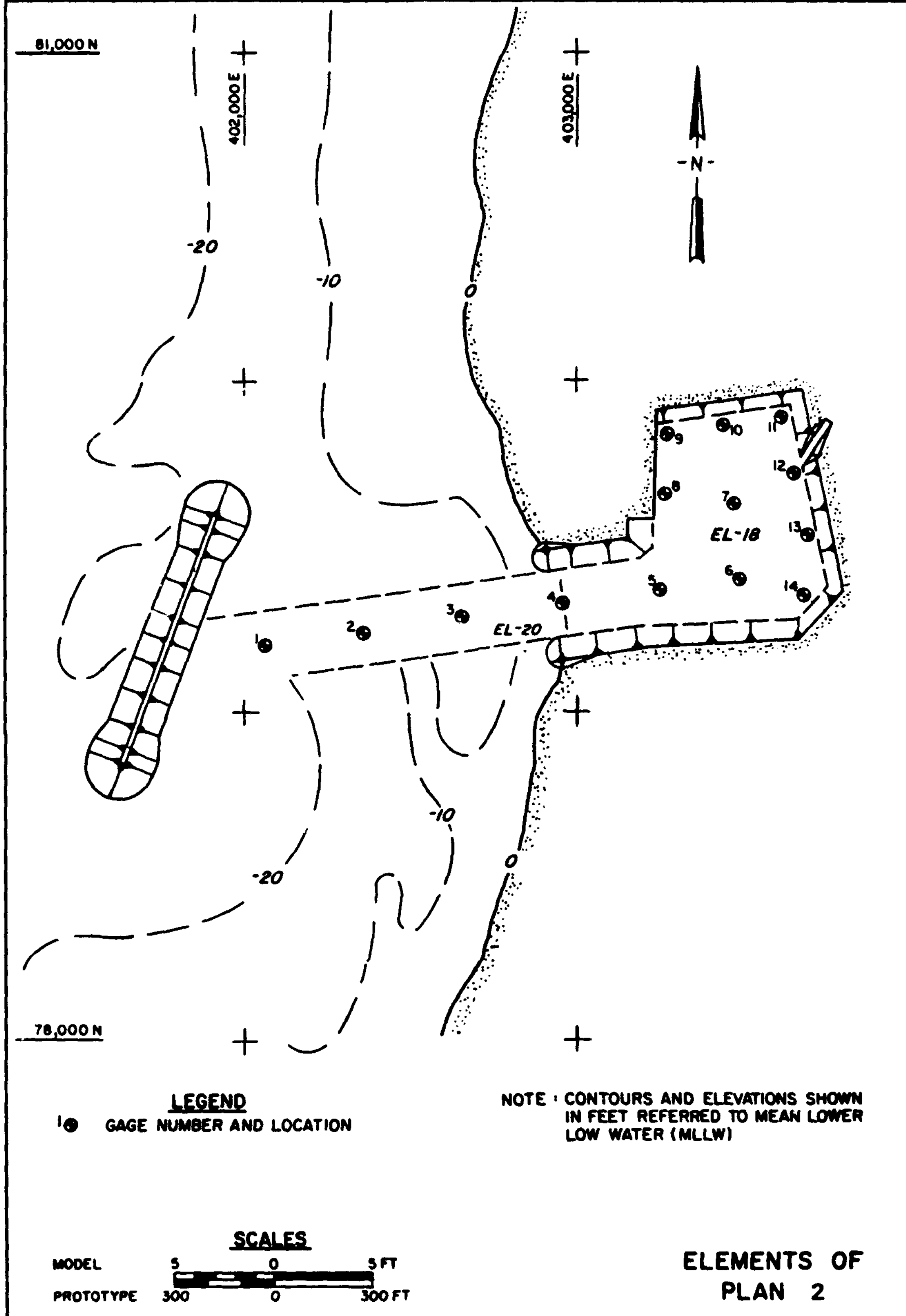
SCALES

MODEL 5 0 5 FT

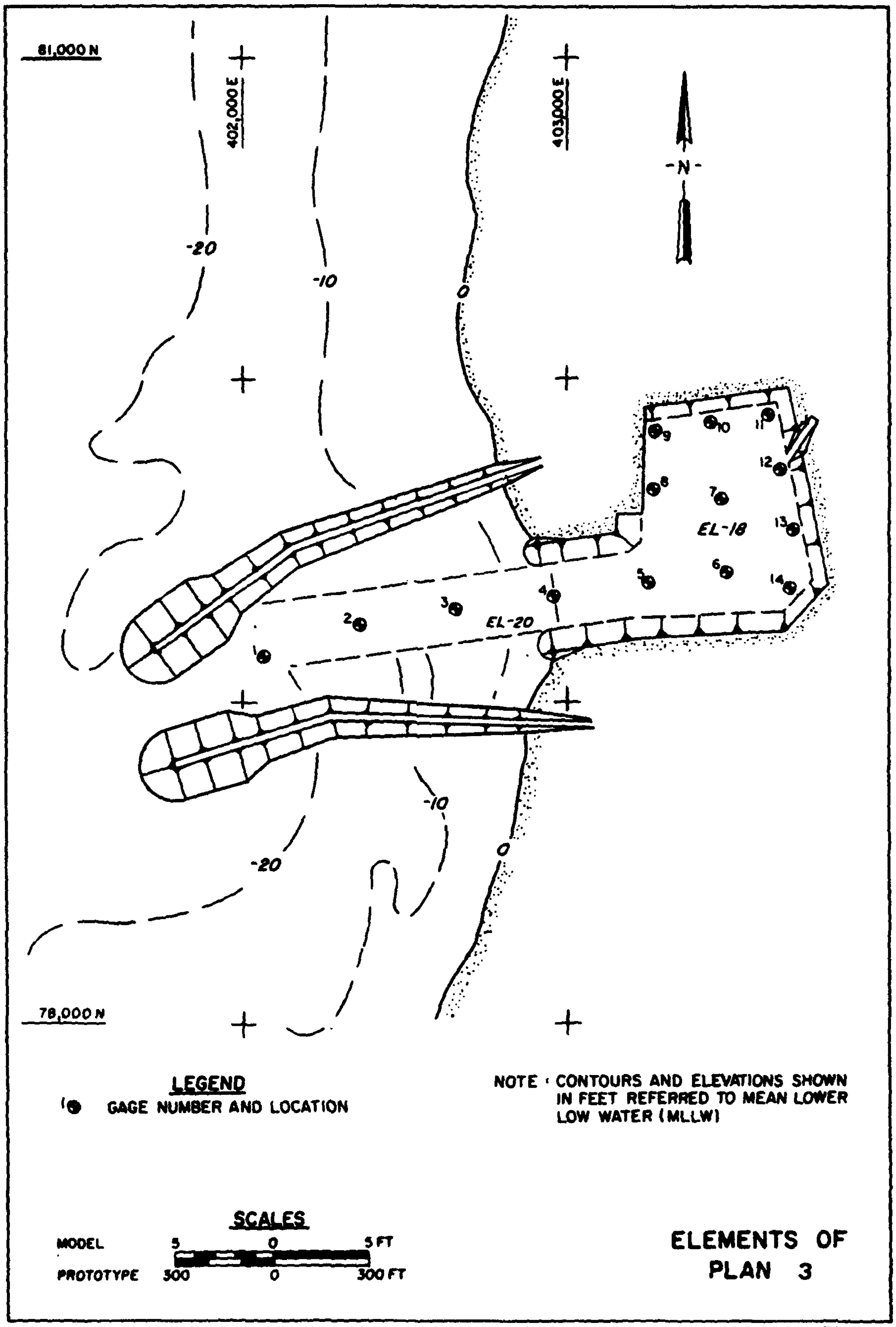
PROTOTYPE 300 0 300 FT

ELEMENTS OF PLAN 1

Plate 1



ELEMENTS OF PLAN 2


81,000 N
402,000 E
403,000 E
-N-
-20
-10
0
EL-18
EL-20
1
2
3
4
5
6
7
8
9
10
11
12
13
14
-10
-20
0
78,000 N
LEGEND
GAGE NUMBER AND LOCATION
NOTE : CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOWER LOW WATER (MLLW)
SCALES
MODEL 5 0 5 FT
PROTOTYPE 300 0 300 FT
ELEMENTS OF PLAN 3

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13. ABSTRACT *(Maximum 200 words)*

A 1:60-scale, three-dimensional hydraulic model was used to investigate the design of a proposed harbor at Barking Sands, Kauai, Hawaii, with respect to wave action and entrance channel shoaling. The model reproduced the proposed harbor, approximately 4,600 ft of the Hawaiian shoreline, and sufficient offshore area in the Pacific Ocean to permit generation of the required test waves. One harbor configuration with two breakwater plans was tested. An 80-ft-long unidirectional, spectral wave generator, an automated data acquisition and control system, and a crushed coal tracer material were used in model operation. It was concluded from test results that:

a. For the harbor basin and entrance channel with no structures installed (Plan 1), wave heights in the berthing area will exceed the established 1.5-ft criterion for test waves from all five test directions.

b. For the harbor basin and entrance channel with no structures installed (Plan 1), sediment will migrate into the entrance channel for test waves from all five directions.

c. For the offshore breakwater plan (Plan 2), wave heights in the berthing area will exceed the established criterion for test waves from the predominant northwest direction.

(Continued)

14. SUBJECT TERMS
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Harbor shoaling
Harbors, Hawaii
Hydraulic models
Wave protection

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13. (Concluded)

d. For the offshore breakwater plan (Plan 2), sediment tracer north of the harbor will migrate southerly into the entrance channel for test waves from the predominant northwest direction.

e. For the dual shore-connected breakwater plan (Plan 3), wave heights will exceed the criterion in the berthing area by only 0.1 ft at one location.

f. For the dual shore-connected breakwater plan (Plan 3), no appreciable shoaling of the harbor entrance will occur.